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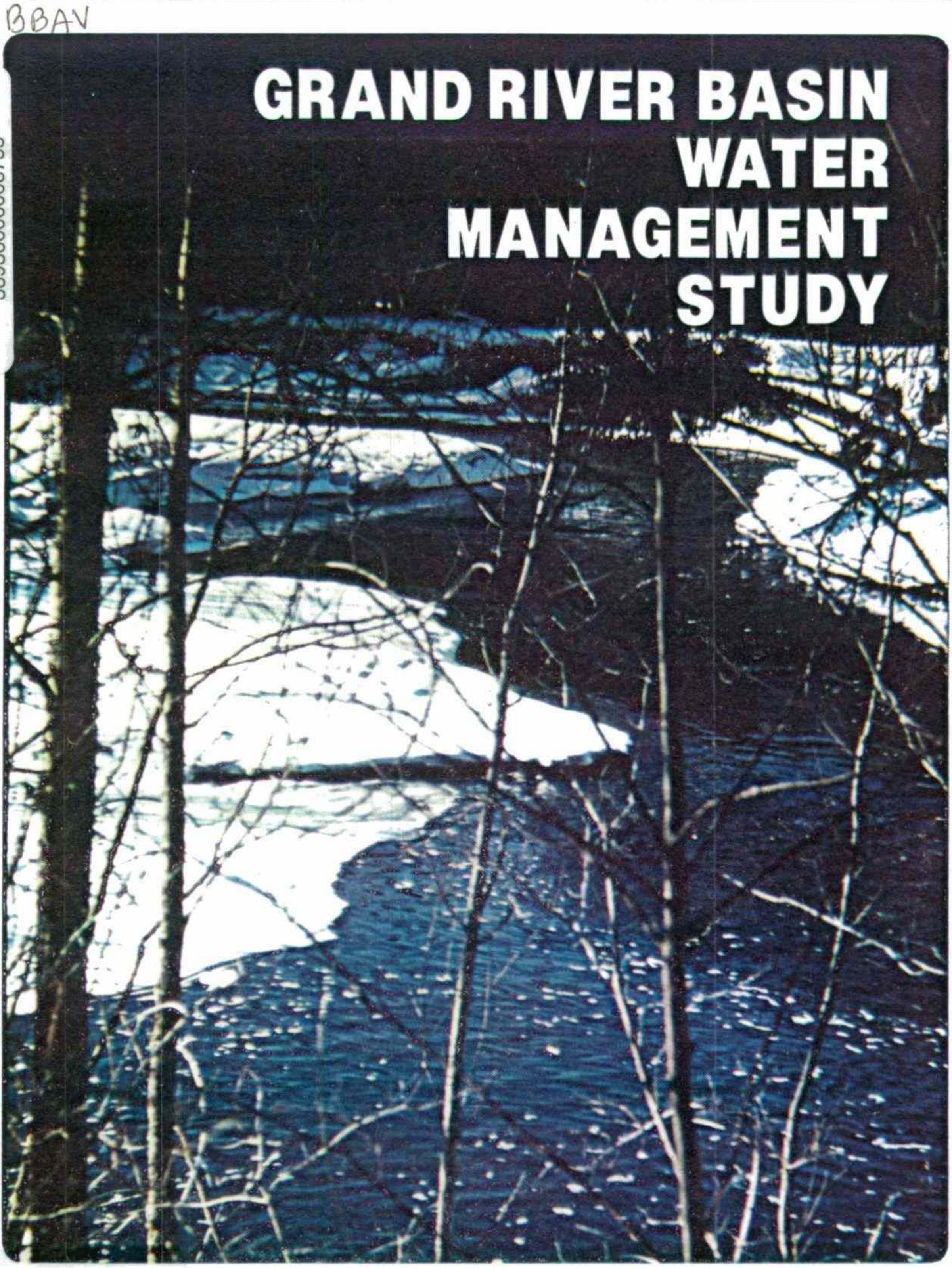

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EVALUATION OF THREE SELECTED WATERSHED MODELS

TECHNICAL REPORT № 6

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GRAND RIVER IMPLEMENTATION
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watershed models for use in
water resources management
studies in the Grand River basin

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GRAND RIVER BASIN WATER MANAGEMENT STUDY
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TECHNICAL REPORT SERIES

REPORT # 6

AN EVALUATION OF THREE SELECTED WATERSHED MODELS FOR USE IN WATER RESOURCES MANAGEMENT STUDIES IN THE GRAND RIVER BASIN

PREPARED FOR THE GRAND RIVER IMPLEMENTATION COMMITTEE BY:

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April 1979

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FOREWORD

This report is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken by the Grand River Hydrology Sub-Committee at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information and in itself does not necessarily constitute policy or management practices. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this report but should be analysed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Basin Water Management Study, Water Resources Branch, Ministry of the Environment, 135 St. Clair Avenue West, Toronto.

ACKNOWLEDGEMENTS

Simulations by the TVA model were carried out by Mr. S. Hancock and the results were interpreted by Dr. L.A. Logan. Programming support for the SQGRID model simulations was provided by Mr. M. Lee and Ms. S. Paul. Ms. S. Paul also wrote the Appendix B on SQGRID model. This report was reviewed by Mr. F.C. Fleischer and Dr. L.A. Logan of the Water Modelling Section, and members of the Hydrology Sub-Committee.

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SUMMARY

1. The three watershed models MOEHYDR2, SQGRID and TVA are reviewed and evaluated for their applicability in the Grand River basin. Qualitative evaluations are given in Chapter 3, whereas Chapters 4, 5 and 6 deal with calibration, prediction and discussion of results. Description of parameters involved in each model and sample outputs are presented in Appendices A, B and C.

2. The models are calibrated on test basins: Eramosa River, Lutteral Creek and Nith River. Only the Eramosa River sub-basin serves as a common basin among all three models. The MOEHYDR2 and SQGRID models are calibrated and compared using the Lutteral Creek sub-basin and the former is calibrated and evaluated further in the Nith River sub-basin.

3. A direct comparison between the MOEHYDR2 and the SQGRID models for hourly simulations shows the models yield results which are quite comparable. The SQGRID model predicts peak flows for specific storms with reasonable accuracy. The MOEHYDR2 is more attractive because less CPU time is required. For the Eramosa River sub-basin, the cost of simulation by the SQGRID model is approximately seven times that of the MOEHYDR2 model.

4. On a seasonal basis, the daily flows predicted by the MOEHYDR2 model are satisfactory (See figure 5.1). The SQGRID model cannot be used for direct, daily simulations because the time step is restricted by the grid size chosen.

5. The MOEHYDR2 model is recommended for daily flow simulations for periods up to one year and for situations where a continuous simulation of both daily and hourly flows is required in combination. In the SQGRID model, the computations are performed hourly in each of the grids in sequence and the computer costs are high. This model, therefore, is not suitable when the simulations are required over a long period.

6. By interfacing with a suitable precipitation forecasting system, SQGRID should form a good flood forecasting model. The SQGRID model is also useful in studying the effects of changes in the distribution of some physical characteristics of the watershed, such as infiltration rates or land use.

7. The TVA model is recommended for long term simulations where average monthly flows will satisfy the flow requirements.

8. The qualitative aspects of the three models and their performance in simulating flows are summarized in the table on the next page.

MODEL QUALITIES AND SIMULATIONS OF FLOWS

Criteria	MOEHYDR2	SQGRID	TVA
Applicability			
1. Water balance studies	Good	Fair	Poor
2. Water management study flow simulation for:			
-days	Good	Good	Fair
-months	Good	-	Good
-years	Fair	-	Good
3. Accommodation of local changes in watershed characteristics			
-physical	Fair	Good	Poor
-hydrometeorological information	Fair	Fair	Fair
4. Snowmelt routine interface	Good	Fair	Fair
5. Continuous long and short term simulaton	Good	Poor	Poor
6. Transfer to ungauged sub-basins	Fair	Poor	Fair
7. Input data availability	Good	Good	Good
8. Flood forecasting	Good	Good	Fair
9. Adaptation to different computer systems	Good	Good	Good
10. Computer costs	Good	Poor	Good
Simulation Performance			
11. Mean monthly flow	Good	-	Good
12. Mean daily flow	Good	Good	Fair
13. Peak flows			
-hourly	Good	Good	-
-daily	Fair	-	Fair
14. Low flows	Good	Poor	Fair

1. INTRODUCTION

1.1 Purpose of Report

Based on the need for integrated water management actions, the Grand River Implementation Committee is co-ordinating a study to provide the necessary information for planning and development of the water and related land resources in the Grand River basin. The study deals with the important aspects such as flood control, water quality, pollution control, waste assimilation, water supply and flow augmentation within a general framework of a water resources management program for the basin. Implementation and use of hydrological models for the simulation of hydrologic regimes and applications in water resources management form a part of the study.

During 1976/77, three watershed models were implemented for comparison and evaluation of their applicability in the Grand River water management program. This report presents the results of that study. Subsequent to this study, another model, the National Weather Service River Forecasting System (NWSRFS) was implemented, the results of which shall be presented in a separate report.

1.2 Watershed Models

A watershed model is a streamflow simulation model in which due consideration is given to the physical processes taking place in the rainfall-runoff phase of the hydrologic cycle. In this case, the inputs are usually the meteorological variables and the model transforms the inputs into streamflows.

The analysis of rainfall-runoff processes of a drainage basin is complex and simulation models require the development of relationships necessary for the conversion of meteorological inputs into runoff. Watershed models are normally based on a combination of deterministic and parametric techniques.

2. REVIEW OF THE SELECTED STREAMFLOW SIMULATION MODELS

2.1 Selection of the Models

Different kinds of water resources and hydrologic models are being developed by various agencies. These models are developed to aid in the solution of either a specific problem or a set of problem situations. The choice of a particular model for application in solving a specific problem may depend on the overall development goal and objectives of the project. The prerequisite to the choice of a hydrologic model requires a clear definition of the main objective of the water resources management program. Furthermore, the model selected should be sufficiently flexible in operation so as to allow for its use for several purposes, with minor modifications.

The choice of a suitable watershed model for application in hydrological studies in the Grand River Basin is important. Though numerous watershed models are reported in literature (WMO, 1975) not all of them meet the needs and requirements of the hydrological investigation for the Grand River Basin Water Management Study. The watershed model, in addition to the simulation of river flows, should be capable of simulating, with reasonable accuracy, various other components of the hydrologic cycle so that the model can be used in ground water and other water balance studies.

In this preliminary report, three models are investigated for their applicability in the Grand River basin. The choice of these three models is based on easy accessibility and familiarity of the models to the working group, and the computer hardware requirements. Furthermore, two of the models selected (MOEHYDR2[1] and SQGRID[2]) were developed in Canada and were cited to give satisfactory results for basins in Canada. The third model (TVA[3]) was developed in the United States of America and has been applied for water resources management studies of small basins in the Tennessee Valley area. It can be noted that each of the models under consideration belongs to a different category; namely they can be considered as a lumped model, distributed model and an index model, respectively.

[1] Comprehensive watershed model (lumped, deterministic) - Ontario Ministry of the Environment

[2] Rainfall-runoff watershed model (distributed, parametric) - University of Waterloo.

[3] Total rainfall-runoff watershed model (lumped, index parametric) - Tennessee Valley Authority, Tennessee, U.S.A.

2.2 Review of the Models

2.2.1 Lumped Model-MOEHYDR2

The model "MOEHYDR2" is a computer program package for the simulation of a comprehensive watershed hydrologic system. The model was developed by the Water Modelling Section of the Ministry of the Environment. The model is formulated to represent, as well as practicable, concepts of the interrelationships of the various hydrologic processes in the watershed (Logan, 1972). Test applications were completed in International Hydrological Decade (IHD) representative basins in southern Ontario.

(a) Model Structure

The schematized form of the model structure is shown in Figure 2.1 As indicated in the figure, the precipitation (including excess snowmelt) is processed through the various functions of interception, surface depression and detention storages, infiltration, ground water and surface runoff components. The infiltrated portion of the precipitation, after satisfying the maximum storage requirements of the aeration and interflow zones, contributes to the accretion of the ground water storage. The total of surface flow, interflow and the baseflow is routed to produce the total runoff at the outlet of the basin. The model package comprises three major sub-models: one for daily simulation (LTSM), another for hourly simulation (STSM) during specified storm event periods and the other for simulating snow accumulation and melt (SNMELT). All of the three submodels are interfaced for continuous daily simulation for a period of up to 366 days. In the hourly simulation mode, any number of days corresponding to a selected storm event may be included as desired. The MOEHYDR2 model is a lumped, deterministic, parametric model; and the simulations are carried out for average input conditions of the basin. Estimates of the most sensitive model parameters are calculated based on a trial-and-error basis supplemented by automatic optimization procedures. In the automatic procedure, the function which is optimized is the sum of squares of the differences between simulated and observed flows. The optimization is carried out by an automatic "pattern search" optimization routine.

(b) Sub-model LTSM

The LTSM sub-model is used in the daily flow simulation mode of MOEHYDR2. In this mode, seven parameters are optimized, five of which are related to infiltration and surface runoff components, and the other two deal with ground water storage and baseflow calculations. A complete list and description of model parameters and constants used in the model are given in Appendix A.

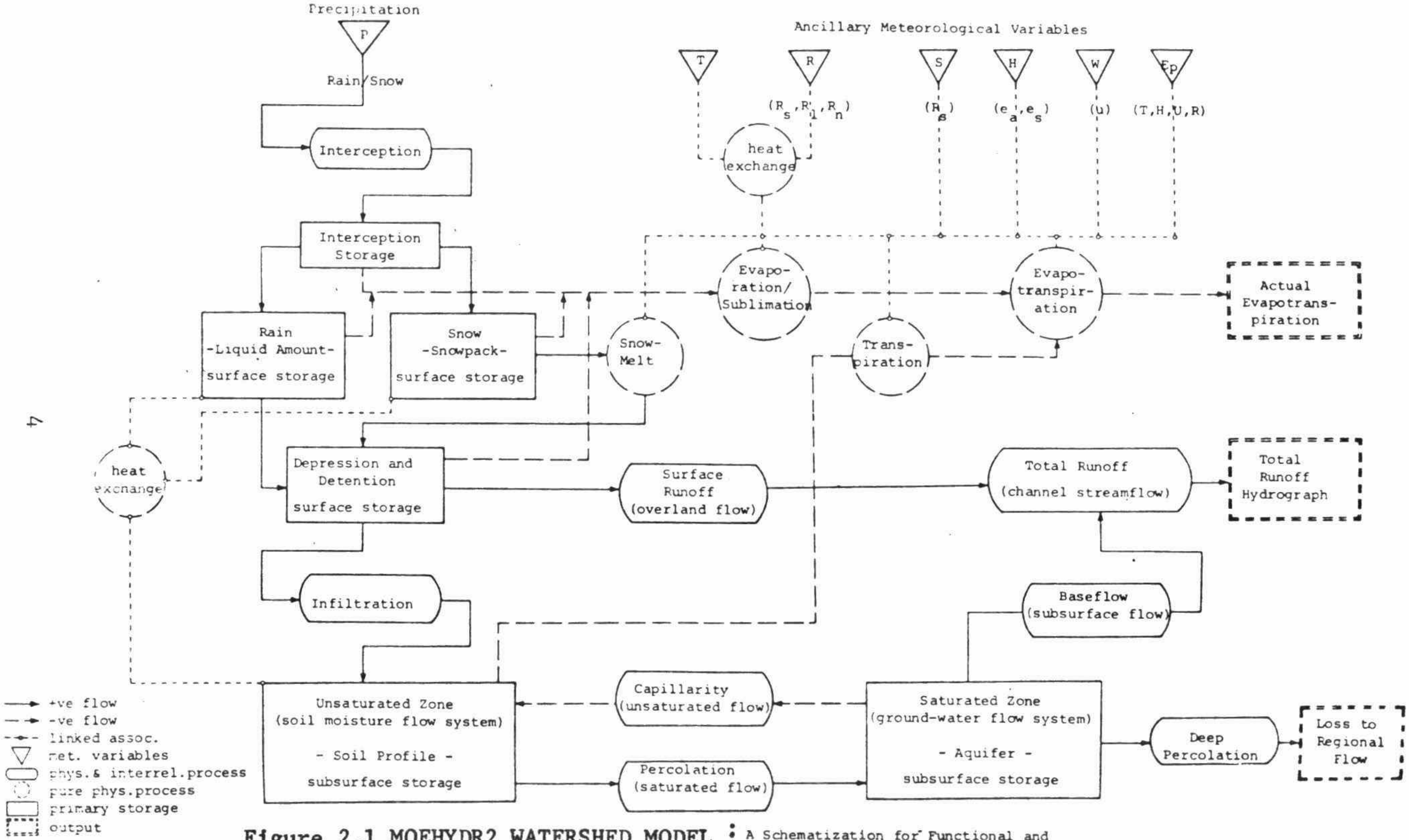

Precipitation
P
Rain/Snow
Ancillary Meteorological Variables
T
R
S
H
W
Ep
(R_s, R_l, R_n)
(R_s)
(e_a, e_s)
(u)
(T,H,U,R)
heat exchange
Interception
Interception Storage
Rain -Liquid Amount- surface storage
Snow -Snowpack- surface storage
Snow-Melt
Evaporation/ Sublimation
Transpiration
Evapotranspiration
Actual Evapotranspiration
heat exchange
Depression and Detention surface storage
Surface Runoff (overland flow)
Total Runoff (channel streamflow)
Total Runoff Hydrograph
Infiltration
Baseflow (subsurface flow)
Unsaturated Zone (soil moisture flow system) - Soil Profile - subsurface storage
Capillarity (unsaturated flow)
Saturated Zone (ground-water flow system) - Aquifer - subsurface storage
Percolation (saturated flow)
Deep Percolation
Loss to Regional Flow
+ve flow
-ve flow
linked assoc.
met. variables
phys.& interrel.process
pure phys.process
primary storage
output

Figure 2.1 MOEHYDR2 WATERSHED MODEL : A Schematization for Functional and Inter-related Hydrologic Processes

(from Logan, 1972)

(c) Sub-model STSM

The STSM sub-model is used in the hourly flow simulation mode of MOEHYDR2. The method of computation is essentially the same as that contained in the LTSM sub-model, except that some different algorithms are used for some of the calculations which are performed hourly during the designated storm dates. The optimization routine considers five parameters, three of which are related to infiltration and the other two are used in the surface runoff routing calculations (Appendix A).

(d) Sub-model SNMELT

This sub-model simulates the snow accumulations during the winter months and calcuates the excess melt from the accumulated snow on a daily basis. The method of melt calculations is based on energy balance principles and the sub-model is programmed to function on its own. It is then possible to interface this sub-model with any comprehensive watershed model. Further details on the snowmelt routine are presented by Logan (1976).

(e) Input Requirements

The input requirements for model initialization and application fall into five different categories of specification.

(i) Model Control Variables

Model control variables include the types of data sets used, start and end date of simulation period (accommodating leap and non-leap year), specification for selected input storm event sequences and monthly variation of average daily maximum sunshine hours.

(ii)Data Input Variables

Data input variables are meteorological and streamflow data for use in calibration or only meteorological input for use in simulation and prediction.

For the LTSM sub-model the input are daily precipitation (total) and estimates of potential evaporation.

For the SNMELT sub-model, in addition to daily precipitation (rain and/or snow), daily input of air temperature, relative humidity, net radiation and wind speed are required.

(iii) Optimization Control Variables

These variables include the number of parameters to be optimized, number of observations, number of iterations, type of objective function to be used, incrementor, decrementor and limit values for the parameters and test level of convergence. They specify control for optimization of LTSM or STSM sub-model parameters and specification for the desired output summary options.

(iv) Watershed Model Constants

These include physical basin parameters (area, flow path length, etc.), empirical constants and coefficients (soil moisture field capacity, wilting point, snowmelt coefficients, etc.).

(v) Initialization Variables

These include initial basin storage condition (soil, ground water, snowpack, flows, etc.) and initial values for model parameters. Definitions of the model constants required for the input are listed in Appendix A.

(f) Data Processing

The necessary meteorological data can be obtained in the form of punched cards or on tapes from the federal, Atmospheric Environment Service, Canada. Depending on the distribution of the meteorological stations within and around the basin, weighted average values may be used. As a complement to the application of MOEHYDR2, a computer program was developed to read the magnetic tape supplied by the AES, containing the meteorological data for the different stations. The abstracted data for a particular variable (precipitation or temperature) are used in computing weighted averaged values for the basin. These are provided as punched cards in the input format required by the MOEHYDR2 model. The different station weights are pre-specified inputs to the computer program.

Estimates of values for the various constants and physically based parameters of the model can be obtained from field measurements and published information. Additional and supplementary statistical or empirical analyses are required to determine estimates of a number of less sensitive model coefficients.

(g) Output

In addition to the basic outputs of optimized parameter values and the predicted runoff, the output from the MOEHYDR2 model includes several options in the printout. An important feature of the output is the complete information on the water balance of the river basin printed out for every day of the period of simulation, including the snowmelt periods. For hourly simulations, the same information is provided on an hourly basis. There are ten different output options available.

A list of the different printout options and samples of printouts and plots are given in Appendix A.

2.2.2 Distributed Model - SQGRID

The square grid model is a distributed parametric watershed model, developed at the University of Waterloo for the estimation of river flows from meteorological data (Gupta, 1974). The model is developed as an extension to the distribution of the meteorological data on a grid system superimposed on a basin (Solomon et al 1968). Each grid cell is treated on an individual basis as a "lumped sub-element" within which the physical model parameters are assumed to remain constant.

(a) Model Structure

The hydrologic processes considered in this model, are very similar to those presented in Figure 2.1. However the calculations are performed separately for each grid cell and the flows, computed numerically on the basis of water balance and continuity equations, are routed through the elements in a pre-determined hierarchical order.

The size of a grid in the system can vary from 1 km x 1 km to about 10 km x 10 km, depending upon the size of the watershed. The time step for simulation is 1 hour. It is not possible to use time steps greater than one hour because instabilities may occur when the grid size is small and the velocity of flow within a grid cell is large. The optimizing function is the sum of squares of differences between observed and computed daily flows, the same as in the MOEHYDR2 model. However, an automatic optimization routine "CLIMB" is used instead of a pattern search algorithm.

In the grid model, the contribution to the river flows from ground water storage is not considered. The baseflow contributions resulting from individual storm events is assumed to be negligible, especially at upstream reaches of the stream. However, baseflows are significant when the simulation is carried out over several days over a number of grid elements integrated at the overall basin outlet. In its original form, the square grid model does not include a snowmelt routine and thus is not applicable during winter months. However, it may be possible to interface a suitable snowmelt subroutine with the main simulation model.

The computer package program comprises basin files for the basin drainage configuration and flow network hierarchy, for land use and distribution, for soil types and distribution and for the meteorological input data. A schematic representation of the structure of the computer program and a description of the basin files are given in Appendix B.

(b) Basin Files

BASFI A -	Establish hierarchical level of grid system in drainage basin.
BASFI B -	Overlay the digitized land use and soil data on the grid system on file.
BASFI C -	Delineation of a sub-basin above any point in the system.
BASFI D -	Generates digital and gray map, showing spatial distribution of data.
BASFI E -	Calculates distributed information for soil and land use.

(c) Input Requirements

The input requirements can be divided into four different categories as given below:

(i) Model Control Variables

These relate to specification for designated basin grid location, start and end of simulation period, and optimization criteria.

(ii) Data Input Variables

These include hourly precipitation and air temperature, hourly flows for use in calibration and basin data file inputs (see BASFI description).

(iii) Optimization Control Variables

These include the number of parameters to be optimized, number of iterations, initial value and upper bound for each parameter.

(iv) Initialization Variables

These are initial basin soil moisture and subsurface flow storages.

(d) Data Processing

The necessary meteorological data can be obtained from the Atmospheric Environment Service, Canada. A computer program "EXTRPREC" is used to extract the data and an interpolation program "INTERP" is employed to redistribute precipitation and temperature input to each grid element in accordance with station location and distance to grid element. Daily evaporation rates are calculated, as a function of air temperature, using an empirical equation (Turc's formula).

The values for a number of model constants can be obtained from field measurements and published information.

(e) Output

The simulation output contains a table of hourly estimates of evaporation, soil moisture and ground water storage indices, variable overland and channel lag coefficients and the simulated surface and subsurface components of the runoff. Also included in this table are the hourly inputs of precipitation and temperature for the grid cell under consideration, as calculated by the "INTERP" subroutine. A summary of the simulated daily flows, plot of observed vs. simulated flows and the parameter values are given at the end of the optimization run. There is an additional output option to have the above information printed out at a maximum of four different locations in the basin.

A sample plot of observed vs. simulated flows and a sample printout are included in Appendix B.

2.2.3 Index Model - TVA

The TVA watershed model was developed by the Tennessee Valley Authority, mainly to aid the planning and development of water resources in the tributary areas of the valley. The model was developed and tested in the Upper Bear Creek Experimental Project. This model is an extension of the NWS Coaxial (graphical) Antecedent Precipitation Index method to predict storm runoff from rainfall (Tennessee Valley Authority, 1972).

(a) Model Structure

The model comprises a series of conceptual hydrologic compartments interconnected according to an input-output cascading sequence.

The computer package program consists of a number of simulation algorithms. Lumped retention index relationships for soil and ground water storages are used to determine the fractions of daily precipitation input to surface and subsurface flows. The routing of surface and subsurface flow increments through basin storages is based on empirical lag coefficients. The package program is completed with an automatic optimization routine and a plotting routine. Five primary model parameters undergo automatic optimization, and estimates of another five secondary parameters are made by conventional analytical methods. The optimization routine also provides statistics of goodness of fit for the model. The routines are programmed for continuous daily simulation for a period of up to three years.

The original model does not include a snowmelt routine. Therefore, a simple snowmelt sub-model based on simple degree-day method was interfaced with the main program for simulation during winter months for its application in the Grand River basin.

(b) Input Requirements

The input requirements can be sub-divided into the following groups.

(i) Data Input Variables

The necessary meteorological input for the simulation are daily precipitation, air temperature and monthly estimates of potential evapotranspiration. Daily streamflows are required for the calibration of the model.

(ii) Optimization Variables

These include the number of parameters to be optimized, number of observations, number of iterations, initial values and incrementor and decrementor values and convergence limits for the parameters.

(iii) Model Constants

These are drainage area, seasonal coefficients for interception storage and growth index for crops, land use and distribution indices for soil moisture and ground water availability.

(iv) Initialization Variables

These include initial basin storage conditions (soil moisture, ground water, etc.).

A list and description of the model parameters and constants are given in Appendix C.

(c) Data Processing

Daily precipitation (rainfall) values from a number of stations are processed according to the Theissen polygon weight to determine weighted average input for the basin. In addition, a "precipitation lagging correction" is made to account for the difference in times at which the rainfall and streamflow observations are made.

The program has a "lead-in" period of three months so as to dissipate the effect of incorrect starting values for initial soil moisture storage. During the lead-in period the streamflow data are not required.

(d) Model Output

The output of the TVA model computer program lists, in a tabulated form, daily summaries of rainfall input, components of simulated flows, actual evapotranspiration and volume storage changes for surface moisture, soil moisture and groundwater.

A plotting option is available for daily rainfall input, observed and simulated flows. A summary of the optimized model parameters and a set of goodness-of-fit statistics are also given. Samples of printout and plots are included in Appendix C.

3. MODEL EVALUATION CRITERIA

An evaluation of different watershed simulation models for their applicability in water resources management studies in a particular river basin, should be based on both qualitative and quantitative criteria. A qualitative evaluation can be a comparison of the conceptual aspects of the model and their usefulness in a water management program. A quantitative evaluation can be done by way of model calibration and verification through simulation of flows. For example, the models may be calibrated on the same set of flow data and tested subsequently for their predictive capability with the use of another data set (WMO, 1975). Chapters 4 and 5 of this report deal with such an evaluation.

3.1 Qualitative Evaluation

In a qualitative evaluation of the concepts and functions of the watershed simulation models, the following criteria may be observed for an ideal case:

1. The model should be sufficiently flexible to allow for an interface with other models used in the water management study (e.g. optimization of reservoir operations, water quality, biomass growth, etc.).

2. The model structure should be amenable to modifications so as to accommodate changes taking place in the watershed, whether they be physical or changes in the information being gathered on current hydrometeorological conditions.

3. In addition to the flow simulations, the model should be capable of detailed simulations of various other components of the hydrologic cycle, facilitating also a total water balance study of the basin.

4. The model should have as part of its simulation package a suitable snowmelt routine (for Canadian conditions) so that flow simulation during winter months is possible. Alternatively, the model should be capable of properly interfacing, on-line, with a suitable snowmelt subroutine.

5. The model should be capable of being calibrated on one or more years of daily flows in addition to allowing a calibration on seasonal flow data. An ideal case would be a common set or grouping of optimized parameters allowing a linking of continuous long term and short term simulations.

6. The model should be programmed to function for different time steps, so that short term and long term simulations are possible and this should be performed continuously without interruptions.

7. The model should be able to simulate flows from the entire watershed as well as those from a small sub-basin with a reasonable accuracy and without many changes in the parameter values. This will facilitate application of the model to ungauged sub-basins.

8. The type of input data (meteorological, physiography of the basin, etc.) should be easily obtained by measurements or from standard publications.

9. The model should accommodate both real time simulation and flood forecasting requirements. In the latter case, the structure of the computer program should be adaptable to modification of meteorological data input from other sources such as precipitation data from radar systems.

10. The computer program should be flexible enough to accommodate changes in input/output format and to be run on the most readily available types of computers. Easy access and use of the package program by non-expert hydrological personnel would be an advantage.

The models which are under consideration here do possess some of the qualifications mentioned above, but no single model has all these properties. The MOEHYDR2 and SQGRID models are partly deterministic and parametric and use mathematical relationships based on physical concepts in defining various components of the runoff cycle. The MOEHYDR2 model gives greater details of various component processes, hence the model is useful in water balance studies. The SQGRID model gives details of inflow/outflow components and change in storage for a particular grid element only. On the other hand, the TVA model is based on index methods and does not consider the actual physical processes taking place within the runoff cycle. The values given by the TVA model for the different components are simply indices of moisture allocations by the model.

The SQGRID model is based on hourly simulations and in combination with a large number of grid nodes and extended periods of simulation, computer costs would be excessively high. Such a distributed model is most suited to study situations where physical variations may exist within the watershed and for a case where the simulation extends for a few days only. If the model is properly interfaced with a precipitation forecasting system, it could perform as a useful flood forecasting model.

The MOEHYDR2 model has the capability for both hourly and daily simulation modes with the proper linkage for simulating short term and long term flows in a continuous sequence. Because of the nature of the model (lumped) in the hourly simulation mode, the prediction of peak flows may not be as accurate as those of the SQGRID model.

The TVA model uses daily time steps and because of the method of calculation (index method), it is useful mainly for studying long term simulation. Because of the simplicity of this model, the computer costs of its application in simulation for several years of flows will likely be quite reasonable and the least of the three models considered.

Because of the above review and qualifications, the models are subjectively rated and classified as shown in Table 3.1. In a practical situation, however, all of the above good qualities of the models are dependent on satisfactory and successful calibration. The calibrations of the models are presented in the next chapter.

3.2 Quantitative Evaluation

The quantitative evaluations are based on the following criteria and considerations.

(1) Goodness-of-fit statistics:
  - Correlation coefficient (proportion of variance explained by calibration).
  - differences between means and variances
  - residual mass curve
  - comparison of peak flows and times of occurrence, etc.

(2) Cost of simulation:

  - CPU time for daily simulation
  - CPU time for hourly simulation

TABLE 3.1 Qualitative Model Evaluation

Criteria	Model Applicability and Suitability		
	MOEHYDR2	**SQGRID**	**TVA**
1. Water balance studies	Good	Fair	Poor
2. Water management study flow simulation for:			
-days	Good	Good	Fair
-months	Good	-	Good
-years	Fair	-	Good
3. Accommodation of local changes in watershed characteristics	Fair	Good	Poor
-physical			
-hydrometeorological information	Fair	Fair	Fair
4. Snowmelt routine interface	Good	Fair	Fair
5. Continuous long and short term simulaton	Good	Poor	Poor
6. Transfer to ungauged sub-basins	Fair	Poor	Fair
7. Input data availability	Good	Good	Good
8. Flood forecasting	Good	Good	Fair
9. Adaptation to different computer systems	Good	Good	Good
10. Computer costs	Good	Poor	Good

4. MODEL APPLICATION, CALIBRATION AND RESULTS

4.1 Test Basins

The preselected test basins are the Eramosa River, Lutteral Creek and Nith River. These basins were selected on the basis of representing different physical conditions, in addition to being classified as basins with unregulated flows. A map of the Grand River basin and the different test basins is shown in Figure 4.1.

4.1.1 Eramosa River Sub-basin

The Eramosa River sub-basin has an area of 235 sq. km at the location of streamflow gauging station 02GA029 above Guelph. Streamflow records are available for the period 1962-1977. Only very minor flow regulations are caused by local flow restrictions at Everton and Rockwood. The long term mean flow at the gauging station is 2.33 m^3/s and the recorded maximum and minimum daily discharges are 35.1 m^3/s in 1972 and 0.1 m^3/s in 1964, respectively. The length of the Eramosa River sub-basin is about 37 km and the average width is about 8 km. The river has a length of about 40 km with an average grade of 3 m per km.

4.1.2 Lutteral Creek Sub-basin

Lutteral Creek is a tributary of the Speed River and the sub-basin at the streamflow gauging station 02GA033 near Oustic has a drainage area of 65 sq. km. The streamflow is affected by minor local restrictions. Continuous flow records of daily discharges are available from 1966. The long term mean daily flow is 0.76 m^3/s and between the period 1966-1976 the recorded maximum and minimum daily flows are 13.9 m^3/s in 1972 and 0.01 m^3/s in 1967, respectively. Based on the properties of the Speed and Eramosa Rivers, Lutteral Creek may have a grade of about 3 m per km.

4.1.3 Nith River Sub-basin

The Nith River sub-basin at the streamflow gauging station 02GA10 near Canning has a drainage area of 1031 sq. km. The streamflow is primarily natural, though because of the meandering nature of the stream and gentle slope, a number of naturally occurring oxbows may act as local restrictions. Continuous records of mean daily flows are available from 1948. A set of previous records are available from 1913-1923. The long term mean flow at this location is 10.56 m^3/s with a maximum daily discharge of 328.5 m^3/s in 1950 and a minimum daily discharge of 0.57 m^3/s in 1949 (covering 1948-1976).

The sub-basin is about 72.4 km in length and 16.1 km wide. The stream has a long meandering course, with an average gradient of 1.23 m per km for a total length of 158 km. The climatic conditions of the sub-basin are very similar to that of the entire Grand River basin.

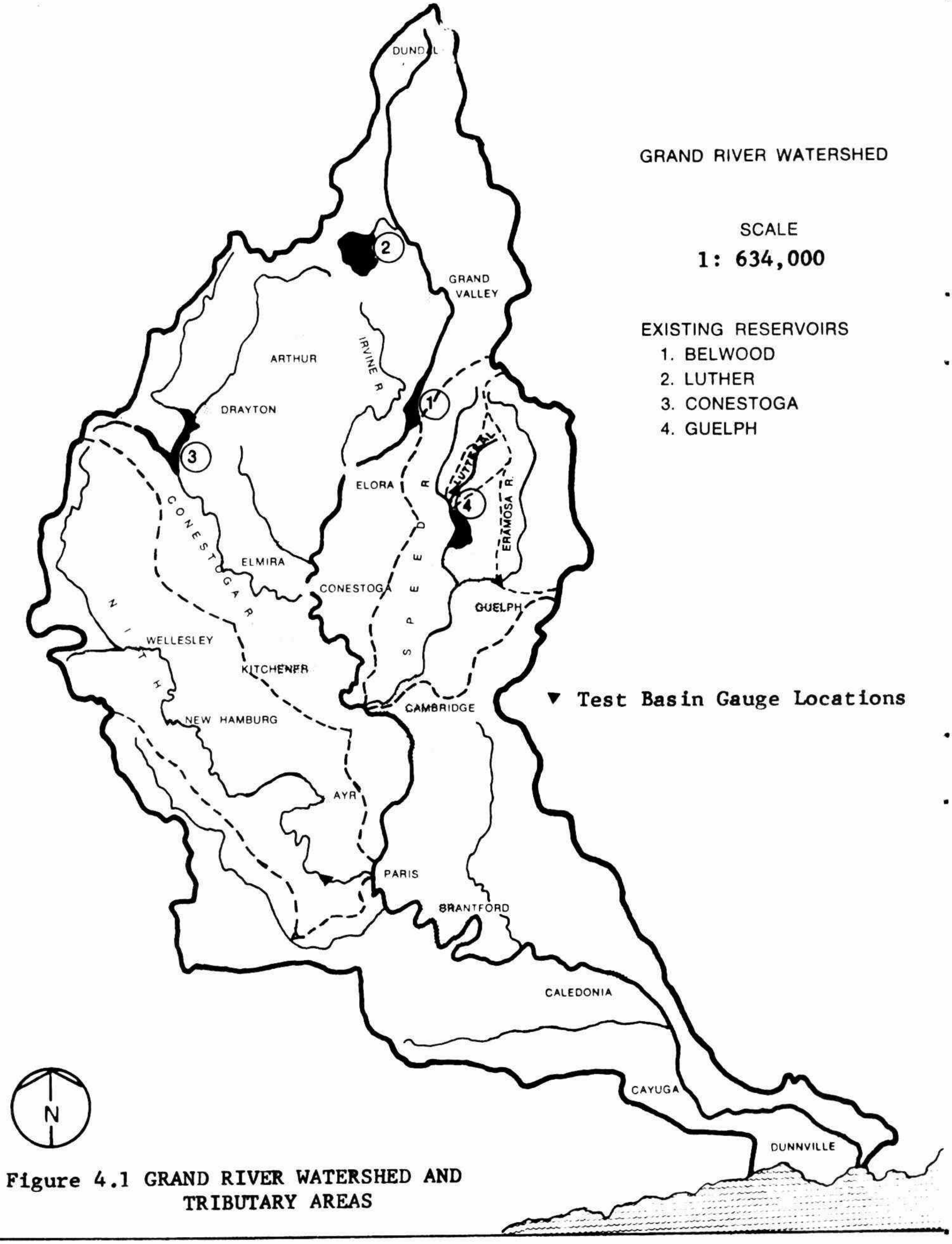


Figure 4.1 GRAND RIVER WATERSHED AND TRIBUTARY AREAS

4.1.4 Climate

There are minor variations in climate throughout the different areas of the Grand River basin. The mean annual temperature ranges from 5.6°C in the north of the watershed, to about 7.8°C in the vicinity of Cayuga and the Lake Erie shoreline. The temperature during the winter months averages about -6°C with the southerly zone slightly warmer than the northern zone. During the summer months, the average temperature varies between 17 and 21°C.

The total precipitation in the watershed during a normal year is about 864 mm, out of which the snowfall is about 229 cm or 229 mm water equivalent. The seasonal distribution of precipitation tends to be regular with the rainfall during May being slightly above the average. The northern half of the watershed lies within the so-called 'snowbelt' of southern Ontario. Heavy snowfalls in this area are common experiences. As a result, the snowpack accumulations with accompanying low temperatures, usually persist on the ground for long periods.

4.2 Calibration of Models

The three models selected are calibrated separately in a single sub-basin (Eramosa) with essentially a common set of data. However, because of the differences in input requirements for the different models, further applications are on a selective basis, depending on the availability of common data sets. The MOEHYDR2 and SQGRID models are calibrated and compared also in Lutteral Creek sub-basin, and the former is calibrated and evaluated further in the Nith River basin.

The calibration involves the determination of an optimal set of model parameters. This is achieved by minimizing the sum of the squared differences between observed and calculated flows.

4.2.1 Eramosa River Sub-basin

The MOEHYDR2 and SQGRID models are calibrated on an hourly basis for a common, single storm, rainfall-runoff event while the TVA model is calibrated on daily precipitation and runoff data.

(i) MOEHYDR2 Model Application

The runoff event selected for the calibration commenced on June 11, 1971. The same event is used to calibrate the SQGRID model, so that a direct comparison of results can be made.

The records of the rainfall event used cover a period of two days on June 13 and 14 with daily total precipitation of 38.6 mm and 19 mm for the 1st and 2nd day, respectively. The hourly distribution of the rainfall exhibits typically a high degree of variability in intensity, with 30.7 mm between 1700 and 1900 hours on the 1st day and 14.7 mm between 0300 and 0400 hours on the 2nd day.

The basin response to the storm gives a satisfactory recorded output hydrograph providing adequate data for the calibration. As only a summer rainfall-runoff event is being considered, calibration is done for the STSM sub-model parameters. The calibration is performed with a combination of coarse trial-and-error runs, with refinement using the automatic optimization sub-routine.

Suitable initial values for the parameters and the initialization variables are chosen and the automatic optimization routine is allowed to go through 20 iterations. Minor adjustments are made to the initial parameter values and the model constants until a reasonable fit is obtained between the observed and simulated hydrographs. Results of the daily mean of the observed and simulated flows and the supporting statistics of fit are given in Table 4.1. The optimized set of parameter values are given in Table 4.2. Suitable estimates of other supporting parameters such as those related to ground water storage and flow are determined separately by calibration runs on the LTSM sub-model routine.

(ii) SQGRID Model Application

The Eramosa sub-basin system is divided into 74 grid elements of 2 km x 2 km size. The model is then calibrated on the runoff event of June 11-18, 1971. In the calibration procedure, suitable initial parameter values are chosen and the values for the model constants are retrieved from the Basin Files (see Appendix B). Recorded hourly flows at the basin outlet are used in the optimizing function. The automatic optimization routine "CLIMBX" is allowed to go through 16 trials after the initial parameter vaues are adjusted until a reasonable fit between the observed and simulateld flows is obtained. Table 4.3 shows the optimized parameter values.

The mean daily values of the observed and simulated flows and the statistics of fit are given in Table 4.1

(iii) TVA Model Application

The calibration of this model is based on daily precipitation inputs and runoff outputs, performed with three years of data. The water-years 1968/69, 1969/70 and 1970/71 are used. Calibration is done separately for each water-year and finally with the combined three years of data. This is done primarily to examine the consistency in the values of the estimated parameters with different, but similar data sets for a given basin. Table 4.4 shows a summary of the parameter values obtained for the various calibrations. It is evident that there is a significant range for each parameter. The lack of consistency in parameter values indicates the optimized set of parameters are highly unique for each data set and may not be satisfactory for long term simulation. Further refinement in the calibration may result in improvement.

Table 4.5 gives the comparison of observed runoff with the simulated values for the three years 68/69, 69/70 and 70/71. The results indicate that total yearly runoff is simulated reasonably well. However, during low flows (monthly) the model simulates flows higher than the observed; the reverse holds for the high flow simulation periods.

TABLE 4.1

Observed and Simulated Flows Using Models MOEHYDR2 and SQGRID Eramosa River Sub-basin

Date	Observed Flow	Simulated (Calibrated) Flow	
		MOEHYDR2 (20 iterations)	SQGRID (16 iterations)
June '71	m^3/s	m^3/s	m^3/s
11.	1.21	1.19	0.02
12.	1.03	1.10	0.07
13.	1.13	1.15	0.99
14.	4.28	6.92	4.39
15.	9.20	7.43	7.26
16.	6.97	4.77	8.99
17.	3.23	3.16	5.72
18.	1.70	2.19	4.37
Mean	3.59	3.49	3.98
Std. Dev.	3.06	2.60	3.36
Correlation Coefficient		0.876	0.848
CPU time		24.9 sec	2 min 17 sec

TABLE 4.2

Optimized Parameter Values for the MOEHYDR2 Model Calibration: Eramosa River Sub-basin (Event: June 11-18, 1971)

Parameter*	Optimized Value
A	10.99 mm/hr
AN	3.82
AL	1.05
NN	0.19
FINC	4.21 mm/hr

* See Appendix A for description

TABLE 4.3

Optimized Parameter Values for the SQGRID Model Calibration:
Eramosa River Sub-basin (Event: June 11-18, 1971)

Parameter*	Optimized Value
FCFRAC	3.63
GWFRAC	0.002
SFCLAG	2.4
SFOLAG	1.71

* See Appendix B

TABLE 4.4

Optimized Parameter Values for the TVA Model Calibration:
Eramosa River Sub-basin (Event: 1968-1971)

	Parameter*				
Water Year	A	D	GWK	TDSRO	B
1968-1969	12.23	96.1	5.75	.182	.751
1969-1970	56.00	26.0	5.70	.075	.327
1970-1971	4.53	74.19	14.25	.168	.272
1968-1971	3.87	52.50	13.47	.153	.286

* See Appendix C

TABLE 4.5

Observed and Simulated Runoff-TVA Model-Daily Simulation: Eramosa River Sub-basin.

	68-69		69-70		70-71	
Month	Observed mm	Simulated mm	Observed mm	Simulated mm	Observed mm	Simulated mm
October	19.23	35.31	7.32	12.75	16.76	17.65
November	30.48	56.39	19.20	36.07	24.16	37.53
December	31.24	47.75	11.33	19.05	34.80	43.95
January	29.97	24.71	9.35	2.21	18.64	4.52
February	30.73	18.44	9.93	1.17	19.99	1.42
March	62.48	53.85	15.44	7.14	32.00	23.93
April	92.46	72.39	71.37	52.07	87.38	71.38
May	43.94	16.94	28.19	21.41	22.61	21.87
June	16.79	12.90	10.59	16.43	22.22	26.67
July	9.93	12.12	8.81	14.86	16.76	27.69
August	8.99	14.15	9.68	14.83	18.39	30.73
September	4.47	10.69	13.31	12.90	11.68	25.40
Total	380.75	375.67	214.63	211.33	325.12	333.25

4.2.2 Lutteral Creek Sub-basin

(i) MOEHYDR2 Model Application

The hourly simulation mode of MOEHYDR2 model is calibrated on the runoff event of October 20-27, 1972. The observed rainfall on the 2nd, 3rd and 4th days amounts to 8.4, 28.5 and 31.8 mm, respectively. The distribution of the rainfall intensity was approximately constant in the order of 2.5 mm/hr during the 3rd and the 4th days. No snowfall was recorded during the event and the potential evaporation varied from 1.02 mm to 4.6 mm/day. The optimization routine is specified with a maximum of 20 iterations and Table 4.6 gives the optimized parameter values.

Table 4.7 gives the daily mean values and the summary statistics for the observed and simulated flows.

(ii) SQGRID Model Application

The Lutteral Creek sub-basin is divided into 16 grid elements of 2 km x 2 km size and the model is calibrated on the runoff event of October 20-27, 1972. Table 4.8 gives the initial and the optimized parameter values. The mean daily values of the observed and simulated flows and the statistics of fit are given in Table 4.7.

TABLE 4.6

Optimized Parameter Values for the MOEHYDR2 Model Calibration: Lutteral Creek Sub-basin (Event: October 20-27, 1972)

Parameter*	Optimized Value
A	2.58 mm/hr
AN	2.38
AL	2.60
NN	0.27
FINC	0.397 mm/hr

* See Appendix A

TABLE 4.7

Observed and Simulated Flows Using Models MOEHYDR2 and SQGRID Lutteral Creek Sub-basin

Date	Observed Flow	Simulated (Calibrated) Flow	
		MOEHYDR2 (20 iterations)	SQGRID (16 iterations)
Oct. 72	m^3/s	m^3/s	m^3/s
20	0.12	0.12	0.08
21	0.13	0.13	0.26
22	0.27	0.15	0.50
23	1.77	0.88	1.51
24	2.05	2.39	2.07
25	1.42	1.50	1.15
26	0.99	0.92	0.97
Mean	0.92	0.89	0.94
St.Dev.	0.76	0.85	0.66
Correlation Coeff.		0.87	0.96
CPU time		22.5 sec	2 min.

4.2.3 Nith River Sub-basin

MOEHYDR2 Model Application

The MOEHYDR2 model is calibrated on daily streamflow data for the period October 1 - December 31, 1974. This calibration is done for the daily simulation mode (LTSM Sub-model). In this mode the parameters which are sensitive to flows, are different from those in the hourly simulation mode. Seven model parameters are optimized after establishing suitable initial values by preliminary and supplementary hydrologic analyses. Refinements in these values are achieved with the automatic optimization sub-routine.

The precipitation data for this period indicated rainfall of 42.2, 87.1, and 8.9 mm, respectively, occurred during October, November and December. The corresponding snowfall amounts are 3.3, 20.3 and 42.4 mm. The average temperature during October was above $0^{o}C$ and that during November was about $-0.5^{o}C$. Temperatures during December were always below $0^{o}C$. The optimized parameter values are given in Table 4.9. The corresponding values of the model constants are given in Appendix A.

Figure 4.2 shows the plot of observed vs. simulated (calibrated) flows for the period under consideration. A visual examination shows that the simulation is reasonably good. The mean and standard deviation of the observed data are 4.13 m^3/s and 1.95 m^3/s respectively and that of the simulated/calibrated data are 4.33 m^3/s and 1.62 m^3/s. The coefficient of correlation is 0.82. The scatter diagram as presented in Figure 4.3, shows that there is a tendency for underestimation of high flows, and a tendency for overestimation of low flows, though less significantly. Further refinements in the model parameters, primarily those dealing with baseflow calculations, through a larger number of optimization runs and a better choice of initial values could improve the fit.

Figure 4.4 shows a plot of the residual mass curves of the observed and simulated flows. The residual mass curve is the cumulative difference between the individial flow (daily) and the mean flow. Thus, the ordinate of the residual mass curve, at any point in time, depends on the history of the preceeding events. Any deviation of the residual mass curve of the estimated flows from that of the observed flows would indicate the existence of systematic errors in the estimated flows. The plots show a reasonable fit during the first half of the simulation period and that systematic errors are introduced during the second half period. Systematic errors are common in rainfall-runoff hydrologic models and a simple test to detect these errors is important in water resources engineering (Aitken, 1973).

TABLE 4.8

Optimized Parameter Values for the SQGRID Model Calibration: Lutteral Creek Sub-basin (Event: October 20-27, 1972)

Parameter*	Optimized Value
FCFRAC	1.027
GWFRAC	0.0138
SFCLAG	0.919
SFOLAG	2.425

* See Appendix B

TABLE 4.9

Optimized Parameter Values for the MOEHYDR2 Model Daily Simulation - Nith River Sub-basin (Event: Oct.1 - Dec. 31, 1974)

Parameter*	Optimized Value
CP	71.12 mm/day
FINC/SHC	24.38 mm/day
EP	0.45
EM	0.40
C1	0.29
CS	0.049
TRANS	0.004 mm/hr

* See Appendix A

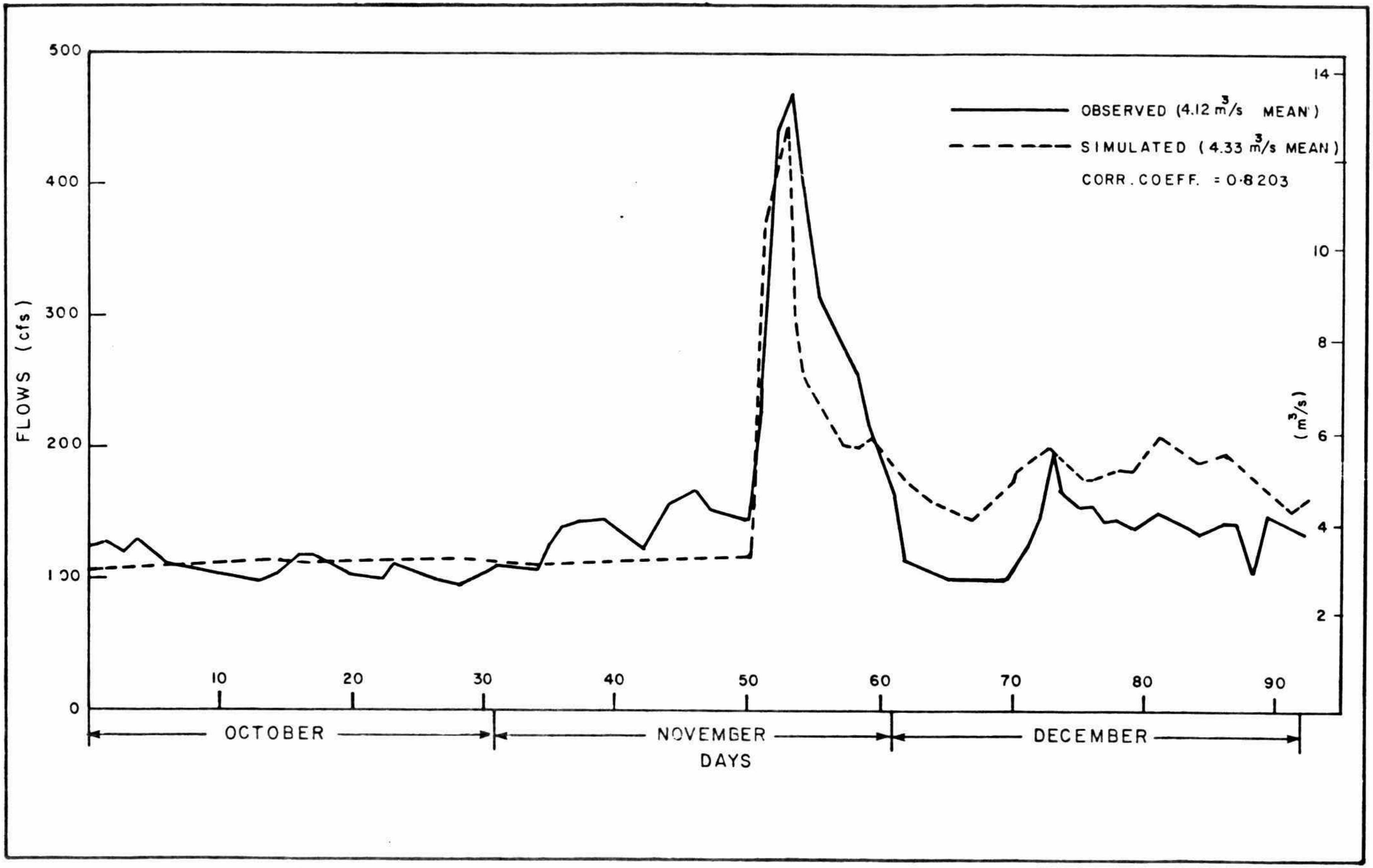


FIGURE 4.2 : OBSERVED AND SIMULATED FLOWS (OCT. 1 - DEC. 31, 1974) NITH RIVER AT CANNING
MOEHYDR 2 MODEL CALIBRATION

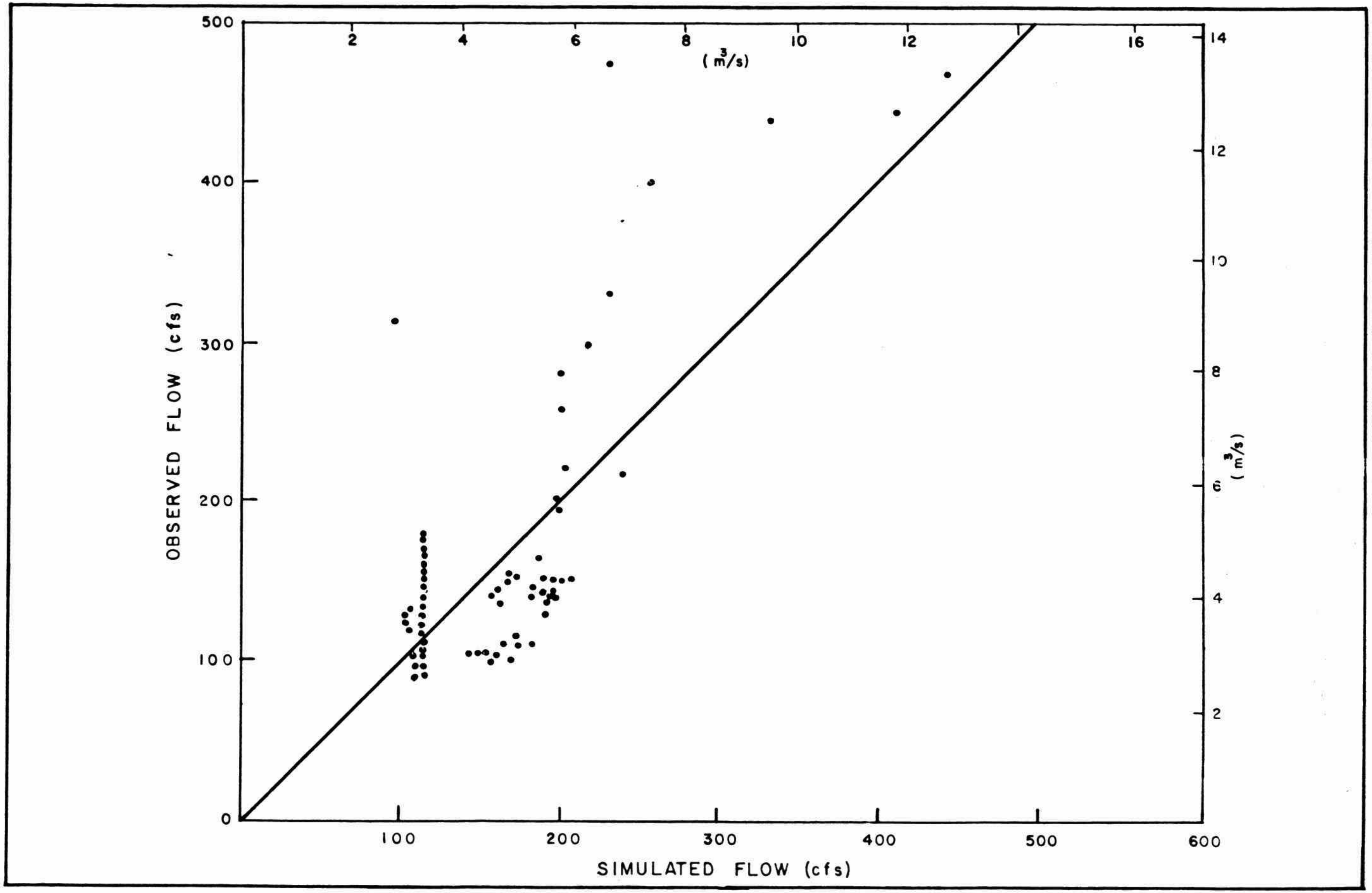


FIGURE 4.3 : SCATTER DIAGRAM — NITH RIVER AT CANNING (OCTOBER 1-DECEMBER 31, 1974)
MOEHYDR 2 MODEL CALIBRATION

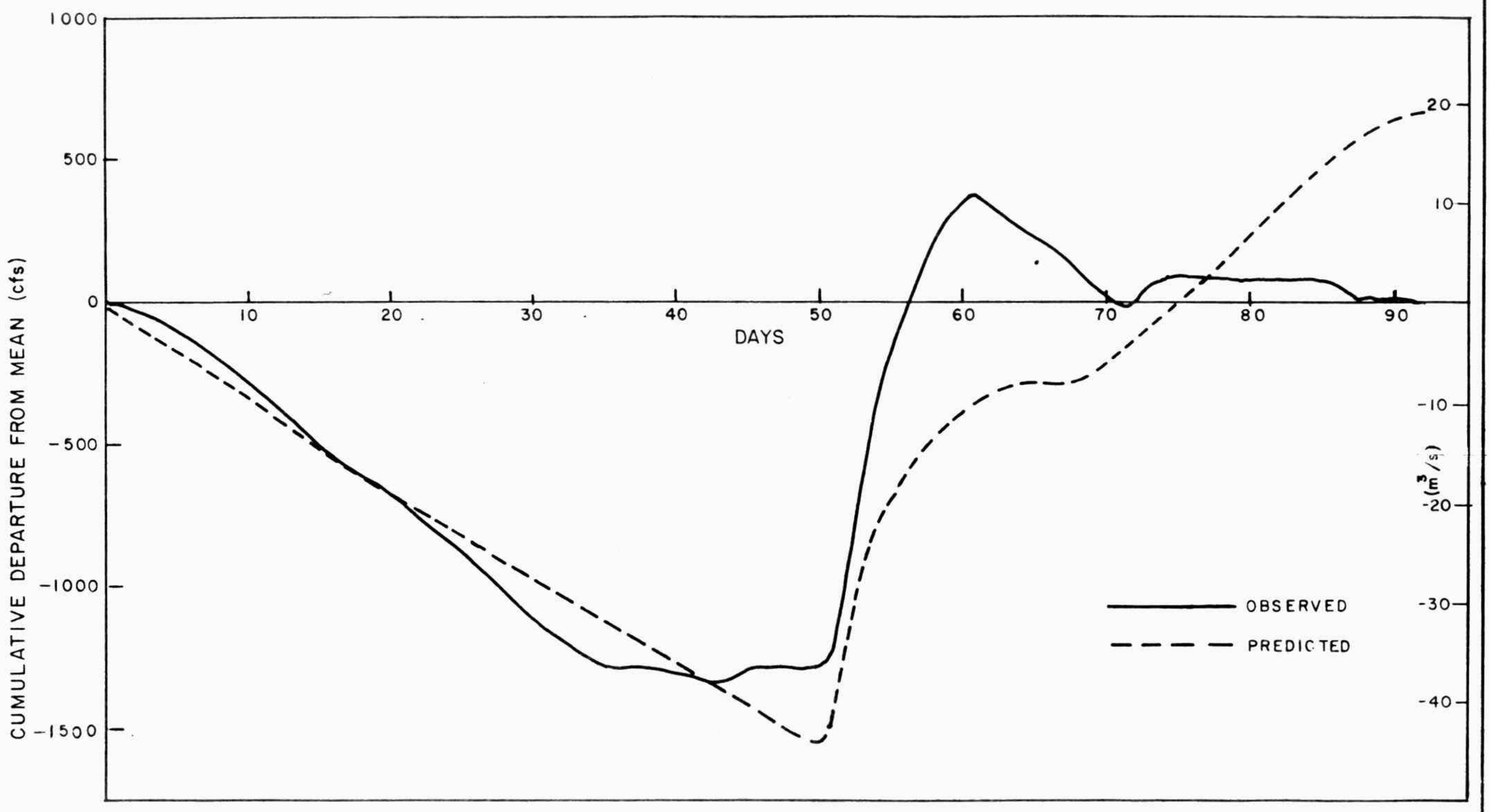


FIGURE 4.4 : RESIDUAL MASS CURVES FOR OBSERVED AND SIMULATED DAILY FLOWS (OCTOBER 1 – DECEMBER 31, 1974) NITH RIVER AT CANNING – MOEHYDR 2 MODEL CALIBRATION

5. MODEL PREDICTION RESULTS

In Chapter 4 the optimized parameter values for the three models, as applicable to the different basins, are given. In this Chapter, the optimized parameters are used to predict flows for a different period.

5.1 MOEHYDR2 Model Predictions

The optimized parameter values for the Nith River sub-basin, as given in Table 4.9, are used to predict daily flows for the period May-July, 1974. The meteorological data for this period include rainfall totals of 124.7 mm, 86.4 mm and 58.7 mm for the months of May, June and July, respectively. There is no record of snowfall during this period. The peak discharge on May 18th results mainly from a rainfall input of 47.5 mm on May 16th. The predicted flows are compared with the observed flows in Figure 5.1. The predicted hydrograh retains the general shape of the observed hydrograph, though the peak flow is underestimated (and hence underestimates the mean flow). There appears to be less than satisfactory predictions of observed minor fluctuations during the low flow period. However, these flow fluctuations could have been accentuated mainly by artificial and local channel storage effects rather than true basin response to precipitation and potential evapotranspiration input. Futhermore, a single period model calibration is not enough to produce sufficient statistics of the model parameters for use in predictions.

5.2 SQGRID Model Predictions

The optimized parameter values for the Eramosa sub-basin in Table 4.3 are used to predict flows for the runoff event of August 25 - September 1, 1971. The mean daily observed and predicted flows are compared in Table 5.1. It can be seen that the predicted low flows do not agree very well with the observed flows. The predicted high flows agree well with the observed values, but lag them by about one day. A shift in peak is also observed in the calibration process. It is therefore presumed that further refinement in calibration may improve the timing of the predicted peak flows.

5.3 TVA Model Predictions

The TVA model, with the optimized parameter values of Table 4.4, is used to predict flows in the Eramosa River and the Speed River. The Eramosa River is a tributary of the Speed River and it is assumed that the Speed River basin has similar physical characteristics as those of the Eramosa River sub-basin. The optimal set of parameter values for the calibration based on the combined three years of data is used (Table 4.4). The observed and predicted monthly runoffs in the Eramosa River for the water year 1971-1972 are given in Table 5.2. The observed and predicted runoffs exhibit relations similar to those indicated by the results of Table 4.5. The yearly total runoff is predicted with reasonable accuracy.

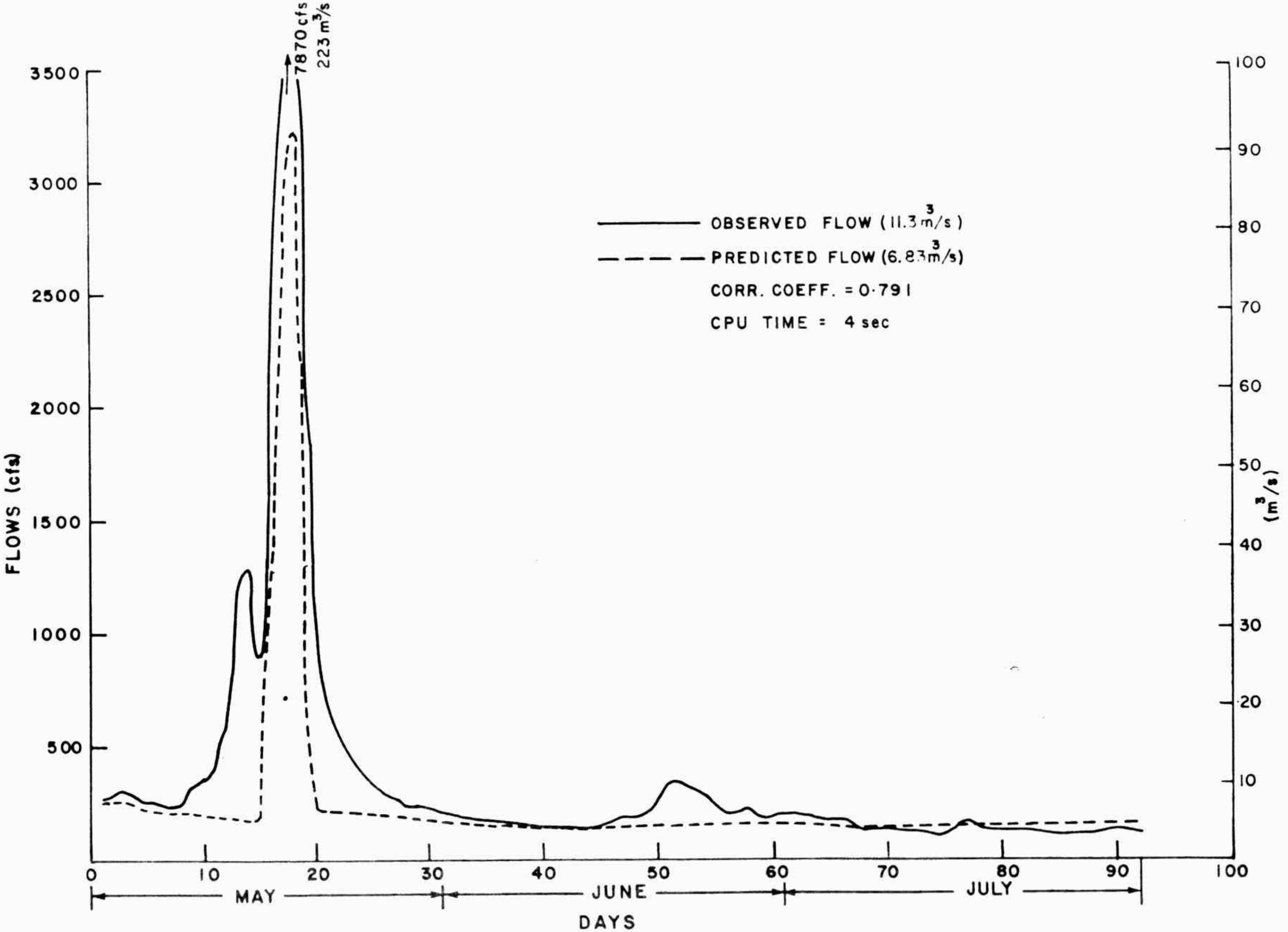


FIGURE 5.1 : OBSERVED Vs PREDICTED FLOWS (MAY 1 - JULY 31, 1974) - NITH RIVER AT CANNING
MOEHYDR 2 MODEL PREDICTION

TABLE 5.1

Observed and Predicted Flows-SQGRID Model
Eramosa Sub-basin (Event: August 25 - September 1, 1971)

Date Aug-Sept '71	Observed Flow m^3/s		Predicted Flow m^3/s
25	0.71		0.05
26	0.89		0.13
27	6.67		1.72
28	8.77		3.94
29	7.44		8.34
30	4.40		6.61
31	2.88		4.49
01	1.71		3.23
Mean	4.12		3.56
Std. Deviation	3.13		2.95
Corr. coefficient		0.565	
CPU Time			8.05 Sec

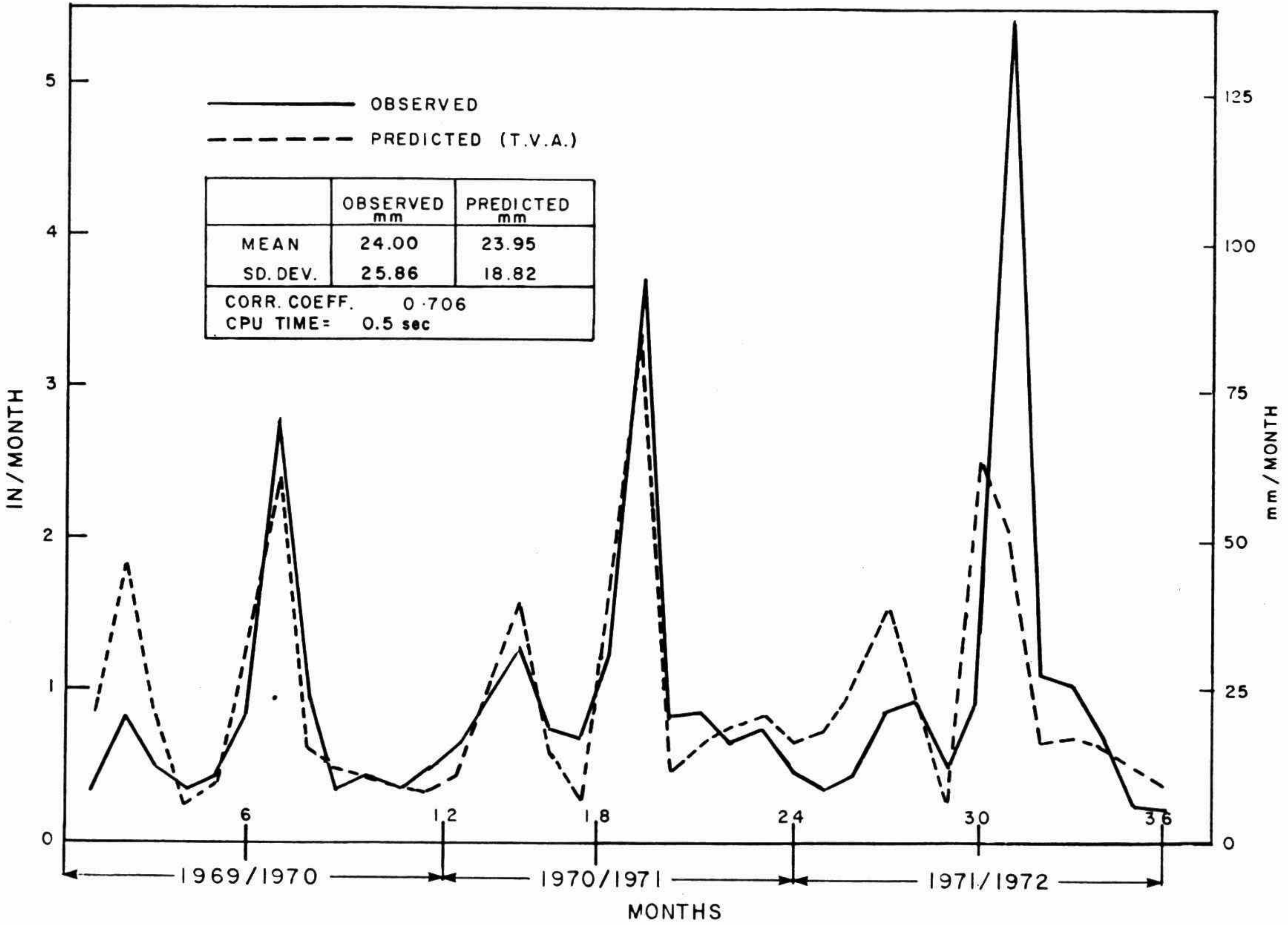
TABLE 5.2

Observed and Predicted Runoff-TVA Model
Eramosa Sub-basin (October 1971 - September 1972)

Month	Observed mm/month		Predicted mm/month
October, 71	9.19		18.11
November, 71	11.66		25.10
December, 71	27.94		48.26
January,72	18.80		15.62
February,72	15.80		3.66
March, 72	24.84		45.97
April, 72	132.08		60.45
May, 72	37.34		35.05
June, 72	25.65		34.29
July, 72	19.41		29.97
August, 72	8.97		22.02
September, 72	8.66		16.84
Mean	28.45		29.46
Std. Dev.	33.78		16.13
Corr. Coeff.		0.719	
CPU Time			0.2 Sec.

In the Speed River basin, the monthly values of the observed and predicted runoffs for the water years 1969-1970, 1970-1971, and 1971-1972 are plotted in Figure 5.2. A visual inspection of the graphs shows that the predicted runoff compares reasonably well with the observed values in many months. Table 5.3 summarizes the statistical analysis for examining the significance of the difference between the observed and predicted flows at the 95 per cent confidence level. The results indicate that for the months February, May, September and October, the predicted flows are statistically significantly different from the observed at the specified significance level.

Based on the limited model prediction results reported herein, the qualities of prediction by the three models are summarized in Table 5.4., together with information on CPU costs.



	OBSERVED mm	PREDICTED mm
MEAN	24.00	23.95
SD. DEV.	25.86	18.82
CORR. COEFF.	0·706	
CPU TIME=	0.5 sec	

FIGURE 5.2 : SPEED RIVER MONTHLY FLOWS OCTOBER 1969 – SEPTEMBER 1972

TABLE 5.3

Statistics of Observed and Predicted Runoff-Speed River 1970-1971 Flows - TVA Model Prediction

	Observed		Predicted		
	Mean mm/day	Std. Dev. mm/day	Mean mm/day	Std. Dev. mm/day	Computed t
October	0.515	0.203	0.358	0.152	3.45
November	0.808	0.305	0.846	0.178	0.59
December	1.054	0.533	1.303	0.686	1.59
January	0.589	0.178	0.467	0.406	1.53
February	0.617	0.127	0.246	0.432	4.35
March	1.069	0.330	1.405	1.346	1.35
April	3.132	1.702	2.964	2.362	0.315
May	0.650	0.305	0.391	0.051	4.67
June	0.724	0.660	0.543	0.279	1.38
July	0.531	0.432	0.63	0.178	1.18
August	0.592	0.787	0.671	0.152	0.56
September	0.391	0.152	0.577	0.051	6.42

TABLE 5.4

Quality of Model Predictions

Criteria	Model		
	MOEHYDR2	SQGRID	TVA
1. Mean monthly flow	Good	--	Good
2. Mean daily flow	Good	Good	Fair
3. Peak flows			
- hourly (storms)	Good	Good	--
- daily	Fair	--	Fair
4. Low flows	Good	Poor	Fair
5. CPU costs for predictions	Moderate	Highest	Lowest

6. DISCUSSION OF RESULTS

The model calibrations presented in Chapter 4, are carried out on one data set for each model. Tests for model predictions are demonstrated in Chapter 5. In a practical situation, the models should be calibrated on data sets from different years. The average values for the parameters determined in these calibrations should be used in predictions. The several calibrations are necessary because the optimized parameter values vary significantly with the different sets of initial parameter values chosen, the model constants and the types of data sets used. These variations in optimized parameter values are particularly significant in complex models where indices of many hydrologic processes are interrelated with one another. The above phenomenon can be observed in Table 4.4 in which the sets of optimized parameter values obtained from the calibration of the TVA model are quite different from one set to another. However, in Table 4.5 all three cases of simulation give reasonable results with respect to the annual mean runoff.

The results of model calibration for the Eramosa sub-basin presented in Table 4.1 indicate that the MOEHYDR2 simulated mean flow and the standard deviation of flows are within three per cent and 15 per cent of the observed flow values, respectively. The corresponding flow statistics values for SQGRID simulations are 11 per cent and 10 per cent respectively. The coefficients of correlation between observed and simulated flows are 0.876 for MOEHYDR2 and 0.848 for SQGRID, respectively. This shows that the simulations are generally good. However, the MOEHYDR2 model underestimates the peak by about 19 per cent and the SQGRID peak flow lags the observed peak by one day. Furthermore, the poor simulations by SQGRID during the initial period may be attributed to the improper accounting of the initial baseflows. The CPU time of 24.9 sec (20 iterations) for the MOEHYDR2 simulation as compared to 2 min 16.9 sec (16 iterations) for the SQGRID simulation makes the MOEHYDR2 model more attractive, depending upon the required accuracy for simulation.

The shortcomings observed above in the results of simulation of Eramosa River flows do not occur in the results of simulation of the Lutteral Creek flows. In Table 4.7, it can be seen that the peak of SQGRID simulated flows coincides with the observed peak and the MOEHYDR2 simulated peak is 16.6 per cent higher than the observed. The coefficient of correlation between observed and simulated flows remains constant for MOEHYDR2, whereas that of SQGRID increases to 0.96. The above calibration shows that the errors introduced may not be a function of the modelling technique itself. Improved simulations can be obtained by a proper choice of initial values for parameters and model constants. Further efforts with the automatic optimization may improve the result of calibration.

The results of simulation of Nith River flows by the daily simulation mode of MOEHYDR2 presented in Figure 4.1, is more encouraging than the results obtained by the hourly simulation mode of MOEHYDR2, when applied to Eramosa River and Lutteral Creek sub-basins, as presented in Tables 4.1 and 4.7. The point that should be noted here is that, with hourly flows, the accuracy of simulation should be greater to get comparative results with that of daily simulations. Furthermore, in the hourly simulated flows, the number of data points available for optimization (8 points in cases here) is less than that for the daily simulation (92 points for Nith River).

The predicted daily flows in the Nith River, presented in Figure 5.1, are reasonably good, noting that the model parameters are obtained after calibration on one data set. The reason for the underestimation of the peak and mean flows may be due to excessive evaporation rates during the peak flow period. The evaporation rates are based on records from the Elora research station which is completely outside the Nith River sub-basin. A check on the water balance shows that for the month of June, about 84 per cent of the total rainfall is lost to evaporation.

An attempt is made also to predict the Nith River flows for one full year, based on the optimized parameter values. However, the predictions (not presented here) are far from satisfactory. This indicates that prediction for longer time periods should be based on calibrations which have data sets of the same time period or longer.

An attempt to calibrate the MOEHYDR2 model for the Nith River sub-basin on one full year's data set (October 74 to September 75) was not successful. The calibration procedure encountered difficulties in the selection of a good set of initial parameter values, so that the optimized values would give flows which are comparable to the observed flows. The drainage area of the Nith River basin, 1031 sq. km, is approximately a fifth of the entire Grand River watershed. The parameters which undergo optimization in the MOEHYDR2 model each represent some physical characteristic of the basin, and may have significant variations spatially and temporally. The selection of a set of parameter values to represent the average conditions of the basin, for all seasons of the year, therefore, becomes an important and very difficult task. After several trial simulations, it is found that the simulated flows compare very well with the observed flows only during a portion of the year (May-September). Since the parameter values are calibrated on one full year's observed flows, they tend to represent average conditions of the basin resulting in an underestimation of peak flows and overestimation of low flows. The means of the observed and simulated flows are, respectively, 11.8 and 9.5 m^3/s which shows the overall mean is underestimated. However, if March and April (months which have high observed peaks, but are severely underestimated) are omitted, then the corresponding values are 10.2 and 10.6 m^3/s, which shows an overestimation. This indicates that if March and April are omitted, a better simulation may be obtained.

These calibrations show that in large basins, the MOEHYDR2 model is easily calibrated when the simulation period is seasonal. Furthermore, it is found that the effort necessary (trial runs, time, etc.) for calibration, is greater when the data set used in calibration has a longer period.

On a yearly data set, the effort necessary to calibrate the TVA model is less than that in case of the MOEHYDR2 model. This is because the parameters of the TVA model are based on empirical equations and they do not represent any actual characteristics of the basin. However, in the TVA model, this may lead to incorrect accounting of the different components (eg. baseflow) of the runoff cycle, even though the total runoff is correctly simulated.

The results presented in Table 5.2, the summary of SQGRID model predicted hourly flows in the Eramosa River, are comparable to the results of calibration given in Table 4.1. The predicted peak is within 5 per cent of the observed peak even though the former one is lagging by one day. This lagging of daily peak flow is also noted in the calibrations. The poor simulations at the beginning of the period may be due to incorrect baseflows which are not considered in the model.

The comparison of observed runoff with TVA model predictions in the Eramosa River, presented in Table 5.3, shows that there is a good agreement between the annual mean flows. However, there are significant differences in the monthly mean values for four months. Imprecisions are reflected also in some of the standard deviations. Based on a daily basis the discrepancies may be higher. The results of predicted runoff in the Speed River, plotted in Figure 5.1, show that the difference between observed and predicted runoff are of the same order of magnitude as that in the Eramosa sub-basin. The poor simulations of the TVA model on a daily basis are revealed in the statistical analysis (Student's t test) given in Table 5.3. This evaluation shows the need for statistical analysis of the observed and predicted flows in order to assess the quality of simulation by a model.

7. CONCLUSIONS

The three watershed models MOEHYDR2, SQGRID and TVA are evaluated both qualitatively and quantitatively for their applicability in the Grand River basin. The qualitative evaluation is given in Chapter 3 whereas Chapters 4, 5 and 6 deal with the quantitative evaluation aspects.

i A direct comparison between the SQGRID model and the MOEHYDR2 model for hourly simulations shows that the models yield results which appear to have the same degree of accuracy. The MOEHYDR2 model is more attractive because of less CPU time involved. In Chapter 3, it is observed that the SRGRID model could be used as a good flood forecasting model. However, in the case of the Grand River basin, the history of flooding reveals that the flooding is mainly due to the snow melting associated with spring rain. Therefore, the SQGRID model can be used to forecast springflood only by interfacing the model with a proper snowmelt routine. Since the ground surface and the top soil conditions during spring will be different from conditions in any other season, it is essential that the model, interfaced with a snowmelt routine, be calibrated on several spring storm flooding events if it is to be used for forecasting.

The MOEHYDR2 model is recommended for daily flow simulations. The SQGRID model cannot be used as a daily simulation model because the time step is restricted by stability criterion based on the grid size. However, the model is useful to study the effect of changes in the distribution of certain specified physical characteristics of the watershed.

ii The TVA model, the least complex model, has small computer time requirements. It is recommended for long term simulations where average monthly flows will satisfy the flow requirements. The TVA model is the only model in which the optimized parameter values can be obtained based on calibration using continuous flow data over several years, and hence will give parameters which are temporally averaged.

iii The MOEHYDR2 model is the one model which has the hourly as well as the daily simulation modes, and hence is applicable in a variety of situations in a comprehensive water resources management program. Furthermore, a snowmelt subroutine is a component of the MOEHYDR2 model.

8. REFERENCES

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APPENDIX A

MOEHYDR2 MODEL

APPENDIX A - MOEHYDR2 MODEL

(i) LTSM Sub-Model - Parameters Optimized

CP = A multiplication constant used in calculating infiltration
EP = An exponent for precipitation used in calculating infiltration
EM = An exponent for soil moisture used in calculating infiltration
TRANS = Transmissibility factor for baseflow calculations
CS = Constant for determining change in depth of water in baseflow storage (index of storage coefficient)
FINC = Steady state infiltration rate
SHC = Steady state percolation rate from interflow zone
C_1 = Critical ratio of volume of water in upper half of layer to storage in total interflow zone layer

(ii) STSM Sub-Model - Parameters Optimized

FINC = Steady state infiltration rate
A = A multiplication coefficient used in calculation of infiltration
AN = An exponent used in calculation of infiltration
AL = A multiplication coefficient used in determining surface runoff
NN = An exponent used in determining surface runoff

(iii) Model Constants

AREA = Drainage area of basin
ISCM = Maximum interception storage capacity
FARIS = Fraction of area assigned to interception storage
DSCM = Maximum depression storage capacity
FARDS = Fraction of area assigned to depression storage
TS = Total storage in the profile
NLAYER= Number of layers in profile not including interflow zone
FCAP = A vector containing the field capacities of each layer in the profile
WP = A vector containing the wilting points of the layers of the profile
ALARGL= Length of stream
ALITL = Average distance of drainage basin to center of stream
HMIN = Minimum depth of water in baseflow storage
K1 = Routing constant for overland flow
K2 = Routing constant for interflow
K3 = Routing constant for baseflow
B = Coefficient used in calculation of evapotranspiration from soil profile
RSRO = Value of routed surface runoff rate
HACT = Depth of water in baseflow storage
M = The number of points in the time-area histogram for lagging channel flow in STSM
TARHIS= Time-area histogram for lagging channel flows in STSM
AAP = Regression constant in snow density-depth relation (accumulation period, no rain)

BAP = Regression coefficient in snow-density-depth relation (accumulation period, no rain)
ARAP = Regression constant in snow density-depth relation (accumulation period, rain)
BRAP = Regression coefficient in snow density-depth relation (accumulation period, rain)
AMP = Regression constant in snow density-depth relation (melt period, no rain)
BMP = Regression coefficient in snow density-depth relation (melt period, no rain)
ARMP = Regression constant in snow density-depth relation (melt period, rain)
BRMP = Regression coefficient in snow density-depth relation (melt period, rain)
BRAP1 = Regression coefficient in snow density-depth relation (accumulation period, rain)
BRMP1 = Regression coefficient in snow density-depth relation (melt period, rain)
BS = Constant used in calculating fraction of interception storage in SNMELT

(iv) Printout Options

Option 1	Table of monthly summary for the different hydrologic component blocks.
Option 2	Table of simulated daily flows.
Option 3	Table of output for the snowmelt sub-model.
Option 4	Table of daily summaries of infiltration and soil moisture storages.
Option 5	Table of daily output and storages for interflow and the baseflow components.
Option 6	Table of daily summaries of the primary hydrologic components of the simulation.
Option 7	Plots of precipitation, soil moisture storages, actual evaporation, observed flows and simulated flows.
Option 8	Plots of simulated snowpack depth, water equivalent and density.
Option 9	Summary of hourly simulations (outputs and storages).
Option 10	Summary of model parameters (including optimized values).

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                                                   WATERSHED/STREAM FLOW SIMULATION

                                                OPTION 1 - MONTHLY SUMMARY OF DAILY SIMULATION

          WATER-YEAR: 1974 TO 1974       MONTH:  0       BASIN: NITH RIVER                GAUGE: 10

                     OCT       NOV       DEC       JAN       FEB       MAR      APRIL      MAY      JUNE      JULY      AUG       SEPT

   TRF-SIM (MM)      6.19     11.93     13.26      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   ACRBF (MM)        6.19      8.25      8.65      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   ACRIFL (MM)       0.0       2.42      4.61      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   RSRO (MM)         0.0       1.26      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   ACTAET (MM)      56.18     24.23      0.79      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   AEIS (MM)         1.80      1.29      1.89      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   AEDS (MM)         1.94      0.00      0.03      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   AEPR (MM)        51.74     22.00      0.25      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   AESP (MM)         0.69      0.94     -1.39      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   ACEMT:P (MM)      2.29     46.14     50.79      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   PS (MM)          31.88     93.69     38.23      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   IS (MM)           1.80      1.29      1.89      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   DS (MM)          11.73     14.12     16.62      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   TDR (MM)          0.0      35.50     50.51      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   SASM (CM)EOM     25.85     30.50     30.50      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   TDDR (MM)         0.0      32.32     45.98      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   DELSASM (MM)    -10.71     46.52      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   VIS (MM)          0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   DELVIS (MM)       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   VDS (MM)          0.0       0.00      0.00      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   DELVDS (MM)       9.79     14.12     16.60      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   ATVIFL (MM)       0.0       3.18      4.53      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   DTVIFL (MM)       0.0       0.77     -0.08      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   DBFS (MM)        -6.19     24.06     37.33      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   HACT (M) EOM    104.11    104.60    105.36      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   P(RAIN) (MM)     42.16     87.12      8.89      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   P(SNOW) (MM)      3.30     20.32     42.42      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   PET (MM)         56.64     26.16      0.76      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

   TRF-OBS (MM)      9.83     16.67     12.11      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0


   BALANCE           0.00     -0.00      0.00      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

    INDICES                   INITIAL VALUE                           END OF PERIOD VALUE

   ANTSM LAYER  1                 7.98 (CM)                                10.17 (CM)
   ANTSM LAYER  2                 8.97 (CM)                                10.17 (CM)
   ANTSM LAYER  3                 9.97 (CM)                                10.17 (CM)
   RBF               0.0      (IN/DAY)  0.0     (MM/DAY)         0.0110 IN/DAY)    0.2803 (MM/DAY)
   RIFL              0.0      (IN/DAY)  0.0     (MM/DAY)         0.0044 IN/DAY)    0.1105 (MM/DAY)

          WATER-YEAR: 1974 TO 1974       MONTH:  0       BASIN: NITH RIVER                GAUGE:

   ***************************************************************************************************************************

     DAY / MONTH     OCT       NOV       DEC       JAN       FEB      MARCH     APRIL      MAY      JUNE      JULY      AUG       SEPT
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OPTION 2

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  1        0.0146   0.2693   0.4153   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  2        0.0420   0.2702   0.3927   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  3        0.0672   0.2710   0.3844   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  4        0.0894   0.2717   0.3757   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  5        0.1093   0.2723   0.3624   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  6        0.1271   0.2728   0.3514   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  7        0.1430   0.2733   0.3793   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  8        0.1572   0.2738   0.4080   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  9        0.1699   0.2741   0.4357   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 10        0.1813   0.2745   0.4546   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 11        0.1915   0.2748   0.4661   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 12        0.2006   0.2751   0.4775   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 13        0.2087   0.2753   0.4460   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 14        0.2160   0.2755   0.4161   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 15        0.2225   0.2757   0.4243   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 16        0.2283   0.2759   0.4392   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 17        0.2336   0.2760   0.4392   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 18        0.2382   0.2762   0.4412   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 19        0.2424   0.2763   0.4756   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 20        0.2461   0.5887   0.5038   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 21        0.2494   0.9847   0.4902   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 22        0.2524   1.0606   0.4689   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 23        0.2551   0.6172   0.4555   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 24        0.2575   0.5564   0.4628   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 25        0.2596   0.5257   0.4669   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 26        0.2615   0.4884   0.4539   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 27        0.2632   0.4831   0.4248   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 28        0.2647   0.4961   0.3989   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 29        0.2661   0.4816   0.3858   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 30        0.2673   0.4452   0.3751   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 31        0.2684   0.0      0.3909   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

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 TRF-SIM (MM)       6.19    11.93    13.26    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 ACRBF (MM)         6.19     8.25     8.65    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 ACRIFL (MM)        0.0      2.42     4.61    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 RSRO (MM)          0.0      1.26     0.0     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 TRF-OBS (MM)       9.83    16.67    12.11    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 DTP:P:EMT MM      45.47   107.82    51.30    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

 P(RAIN) (MM)      42.16    87.12     8.89    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 P(SNOW) (MM)       3.30    20.32    42.42    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 ACTAET (MM)       56.18    24.23     0.79    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 PET (MM)          56.64    26.16     0.76    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 TDR (MM)           0.0     35.50    50.51    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 TDDR (MM)          0.0     32.32    45.98    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 SASM (MM)EUM     258.53   305.04   305.04    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
 HACT (M )EUM     104.11   104.60   105.36    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

 BALANCE           0.0004  -0.0000   0.0000   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
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** HYDROLOGIC MODEL/CALIBRATION - STREAMFLOW SIMULATION

BASIN: NITH RIVER                         GAUGE: 10

OPTION 3 - SNOWMELT SIMULATION: OUTPUT FROM S/MELT ROUTINE

WATER-YEAR:

MONTH:    11


***************************************************************************************************************************************************************
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*DAY *   PRAIN  *   PSNOW   *  AEIS   *  VIS    *  AESP    *   EMT   * DEP1   * DEN1   * WEQ1   *   DTP    *   PS    *  AEDS   *  VDS    *  AET    *  TRF   *
*    *   (MM)   *   (MM)    *  (MM)   *  (MM)   *  (MM)    *   (MM)  * (CM)   *(G/CC)  * (MM)   *   (MM)   *  (MM)   *  (MM)   *  (MM)   *  (MM)   *(CM/S)  *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
***************************************************************************************************************************************************************
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  1 *    0.254*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.254*  0.0    *  0.0    *  0.0    *  0.0    *3.2116*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  2 *    0.0   *      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.0   *  0.0    *  0.0    *  0.0    *  0.0    *3.2219*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  3 *    8.382*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    8.382*  7.747*   0.0    *  0.0    *  0.0    *3.2311*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  4 *    2.286*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    2.286*  1.651*   0.0    *  0.000*   0.0    *3.2393*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  5 *   11.938*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *   11.938* 11.303*   0.0    *  0.0    *  0.0    *3.2467*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  6 *    0.762*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.762*  0.127*   0.0    *  0.000*   0.0    *3.2532*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  7 *    0.0   *      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.0   *  0.0    *  0.0    *  0.000*   0.0    *3.2590*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  8 *    0.0   *      0.0   * 0.1016* 0.0      * -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.0   *  0.0    *  0.000*   0.0    * 15.748*3.2642*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*  9 *    0.0   *      0.0   * 0.0     * 0.0      * -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.0   *  0.0    *  0.0    *  0.0    *  0.0    *3.2689*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
* 10 *    0.0   *      0.0   * 0.0     * 0.0      * -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    0.0   *  0.0    *  0.0    *  0.0    *  0.0    *3.2730*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
* 11 *   11.430*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *   11.430* 10.693*   0.0    *  0.0    *  0.0    *3.2767*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
* 12 *    4.572*      0.0   * 0.0     * 0.1016* -0.1015* 0.0       * 0.0    *0.0     * 0.0    *    4.572*  3.937*   0.0    *  0.000*   0.0    *3.2799*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
* 13 *    2.540*      5.334* 0.1015* 0.0      * -0.1015* 7.9756* 0.0      *0.0     * 0.0    *    7.976*  7.341*   0.0    *  0.0    *  0.000*3.2828*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
* 14 *    0.0   *      1.524* 0.1015* 0.0      *  1.4225* 0.0       * 0.0    *0.0     * 0.0    *    1.524*  0.0    *  0.0    *  0.0    *  7.874*3.2854*
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
*    *          *           *         *         *          *         *        *        *        *          *         *         *         *         *        *
* 15 *    0.0   *      2.794* 0.1015* 0.0      * -0.1015* 2.7940* 0.0      *0.0     * 0.0    *    2.794*  2.159*   0.0    *  0.000*   0.000*3.2877*
```

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** HYDROLOGIC MODEL/CALIBRATION - STREAMFLOW SIMULATION

BASIN:NITH RIVER                              GAUGE:10

OPTION 4 - OUTPUT FROM INFILTRATION AND SOIL PROFILE ROUTINES

WATER-YEAR:

MONTH:   11


**************************************************************************************************************
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*DAY *   P   *  DTP  *   DR  *  DDR  *  AEPR *  ANTSM1  *  ANTSM2  *  ANTSM3  *  SASM *DELSASM*  AET  *  TRF *
*    *  (MM) *  (MM) *  (MM) *  (MM) *  (MM) *   (CM)   *   (CM)   *   (CM)   *  (CM) *  (CM) *  (MM) *(CM/S)*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
**************************************************************************************************************
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  1 *  0.254*  0.254*  0.0  *  0.0  *  0.0  *    8.5199*    7.8607*    9.4720*25.8678* 0.0152* 0.0   * 3.212*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  2 *  0.0  *  0.0  *  0.0  *  0.0  *  0.0  *    8.5352*    7.8607*    9.4720*25.8678* 0.0   * 0.0   * 3.222*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  3 *  8.382*  8.382*  0.0  *  0.0  *  0.0  *    8.5352*    7.8607*    9.4720*26.7060* 0.8382* 0.0   * 3.231*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  4 *  2.286*  2.286*  0.0  *  0.0  *  0.0  *    9.3734*    7.8607*    9.4720*26.9346* 0.2286* 0.0   * 3.239*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  5 * 11.938* 11.938*  0.0  *  0.0  *  0.0  *    9.6020*    7.8607*    9.4720*28.1284* 1.1938* 0.0   * 3.247*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  6 *  0.762*  0.762*  0.0  *  0.0  *  0.0  *   10.1681*    8.4883*    9.4720*28.2046* 0.0762* 0.0   * 3.253*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  7 *  0.0  *  0.0  *  0.0  *  0.0  *  0.0  *   10.1681*    8.5645*    9.4720*28.2046* 0.0   * 0.0   * 3.259*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  8 *  0.0  *  0.0  *  0.0  *  0.0  * 15.646*   10.1681*    8.5645*    9.4720*26.6400*-1.5646*15.7480* 3.264*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*  9 *  0.0  *  0.0  *  0.0  *  0.0  *  0.0  *    8.6035*    8.5645*    9.4720*26.6400* 0.0   * 0.0   * 3.269*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
* 10 *  0.0  *  0.0  *  0.0  *  0.0  *  0.0  *    8.6035*    8.5645*    9.4720*26.6400* 0.0   * 0.0   * 3.273*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
* 11 * 11.430* 11.430*  0.0  *  0.0  *  0.0  *    8.6035*    8.5645*    9.4720*27.7728* 1.1328* 0.0   * 3.277*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
* 12 *  4.572*  4.572*  0.0  *  0.0  *  0.0  *    9.7363*    8.5645*    9.4720*28.2300* 0.4572* 0.0   * 3.280*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
* 13 *  7.976*  7.976*  0.0  *  0.0  *  0.0  *   10.1681*    8.5849*    9.4720*29.0276* 0.7976* 0.0000* 3.283*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
* 14 *  1.524*  1.524*  0.0  *  0.0  *  6.350*   10.1681*    9.3875*    9.4720*28.3926*-0.6350* 7.8740* 3.285*
*    *       *       *       *       *       *          *          *          *       *       *       *      *
*    *       *       *       *       *       *          *          *          *       *       *       *      *
* 15 *  2.794*  2.794*  0.0  *  0.0  *  0.0  *    9.5331*    9.3875*    9.4720*28.6720* 0.2794* 0.0000* 3.288*
```

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** HYDROLOGIC MODEL/CALIBRATION - STREAMFLOW SIMULATION

BASIN:NITH RIVER                                         GAUGE:10

OPTION 5 - OUTPUT FROM INTERFLOW & BASEFLOW STORAGE & ROUTING ROUTINE

WATER-YEAR:

MONTH:   11


*************************************************************************************************************************
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*DAY *  TPS    *  AEDS  *  VDS    *  DR    * VIFL    *  DDR   * RIFL   * RBF   *DIVIFL  * DBFS   * HACT   *TRFSIM*TRF-OBS *
*    * (MM)    * (MM)   * (MM)    * (MM)   * (MM)    * (MM)   * (MM)   * (MM)  * (MM)   * (MM)   *  (M)   *(CM/S)* (CM/S) *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*************************************************************************************************************************
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  1 *  0.0    *  0.0   *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.269*  0.0    * -0.269*104.109* 3.212*   3.110*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  2 *  0.0    *  0.0   *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.270*  0.0    * -0.270*104.103* 3.222*   3.025*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  3 *  7.747* 0.0    *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.271*  0.0    * -0.271*104.098* 3.231*   3.025*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  4 *  1.651* 0.0    *  0.000*  0.0   *  0.0    *  0.0   * 0.0    * 0.272*  0.0    * -0.272*104.092* 3.239*   3.538*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  5 * 11.303* 0.0    *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.272*  0.0    * -0.272*104.086* 3.247*   3.967*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  6 *  0.127* 0.0    *  0.000*  0.0   *  0.0    *  0.0   * 0.0    * 0.273*  0.0    * -0.273*104.081* 3.253*   4.081*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  7 *  0.0    *  0.0   *  0.000*  0.0   *  0.0    *  0.0   * 0.0    * 0.273*  0.0    * -0.273*104.075* 3.259*   4.138*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  8 *  0.0    *  0.000*  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.274*  0.0    * -0.274*104.070* 3.264*   4.138*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*  9 *  0.0    *  0.0   *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.274*  0.0    * -0.274*104.064* 3.269*   3.909*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
* 10 *  0.0    *  0.0   *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.274*  0.0    * -0.274*104.058* 3.273*   3.710*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
* 11 * 10.693* 0.0    *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.275*  0.0    * -0.275*104.053* 3.277*   3.481*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
* 12 *  3.937* 0.0    *  0.000*  0.0   *  0.0    *  0.0   * 0.0    * 0.275*  0.0    * -0.275*104.047* 3.280*   3.881*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
* 13 *  7.341* 0.0    *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.275*  0.0    * -0.275*104.041* 3.283*   4.480*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
* 14 *  0.0    *  0.0   *  0.0    *  0.0   *  0.0    *  0.0   * 0.0    * 0.276*  0.0    * -0.276*104.036* 3.285*   4.680*
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
*    *         *        *         *        *         *        *        *       *        *        *        *       *       *
* 15 *  2.159* 0.0    *  0.000*  0.0   *  0.0    *  0.0   * 0.0    * 0.276*  0.0    * -0.276*104.030* 3.288*   4.766*
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** HYDROLOGIC MODEL/CALIBRATION - STREAMFLOW SIMULATION

BASIN:NITH RIVER              GAUGE:10
OPTION 6 : TABLE - CALIBRATION/SIMULATION - BASIC OUTPUT

WATER-YEAR:

MONTH:   11


*****************************************************************************************************
*     *        *        *         *         *        *        *       *       *       *       *
*DAY  * P(OBS)*EMT/DTP*   PET    *   AET   *  SASM  *TRF(S)*TRF(OBS)*  RBF  * RIFL  * RSRO  *
*     * (MM)   * (MM)   * (MM)    * (MM)    * (CM)   *(CM/S)* (CM/S) * (MM)  * (MM)  * (MM)  *
*     *        *        *         *         *        *        *       *       *       *       *
*****************************************************************************************************
*     *        *        *         *         *        *        *       *       *       *       *
*  1  *  0.254*  0.254*    0.0   *   0.0   * 25.868* 3.212*   3.110* 0.269* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  2  *  0.0   *  0.0   *    0.0   *   0.0   * 25.868* 3.222*   3.025* 0.270* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  3  *  8.382*  8.382*    0.0   *   0.0   * 26.706* 3.231*   3.025* 0.271* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  4  *  2.286*  2.286*    0.0   *   0.0   * 26.935* 3.239*   3.538* 0.272* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  5  * 11.938* 11.938*    0.0   *   0.0   * 28.128* 3.247*   3.967* 0.272* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  6  *  0.762*  0.762*    0.0   *   0.0   * 28.205* 3.253*   4.081* 0.273* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  7  *  0.0   *  0.0   *    0.0   *   0.0   * 28.205* 3.259*   4.138* 0.273* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  8  *  0.0   *  0.0   *  15.748* 15.748* 26.640* 3.264*   4.138* 0.274* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
*  9  *  0.0   *  0.0   *    0.0   *   0.0   * 26.640* 3.269*   3.909* 0.274* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
* 10  *  0.0   *  0.0   *    0.0   *   0.0   * 26.640* 3.273*   3.710* 0.274* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
* 11  * 11.430* 11.430*    0.0   *   0.0   * 27.773* 3.277*   3.481* 0.275* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
* 12  *  4.572*  4.572*    0.0   *   0.0   * 28.230* 3.280*   3.881* 0.275* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
* 13  *  7.976*  7.976*    0.0   *   0.000* 29.028* 3.283*   4.480* 0.275* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
* 14  *  1.524*  1.524*    7.874*   7.874* 28.393* 3.285*   4.680* 0.276* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
* 15  *  2.794*  2.794*    0.0   *   0.000* 28.672* 3.288*   4.766* 0.276* 0.0   * 0.0   *
*     *        *        *         *         *        *        *       *       *       *       *
*     *        *        *         *         *        *        *       *       *       *       *
```

```
                                    ** HYDROLOGIC MODEL/CALIBRATION-STREAMFLOW SIMULATION **

                                             BASIN: NITH RIVER           GAUGE: 10

                             OPTION: SEVEN PLOT - CALIBRATION/SIMULATION OUTPUT(FLOW,AET, & STORAGE)

                                             WATER-YEAR: 1974 TO 1974        MONTH: 11
 1*P                             *           S   *A              *           B                                                     *
 2*P                             *           S   *A              *           B                                                     *
 3*    P                         *            S  *A              *           B                                                     *
 4*P                             *            S  *A              *           B X                                                   *
 5*      P                       *             S *A              *           B  X                                                  *
 6*P                             *             S *A              *            B  X                                                 *
 7*P                             *             S *A              *            B  X                                                 *
 8*P                             *            S  *              A*            B  X                                                 *
 9*P                             *            S  *A              *            B X                                                  *
10*P                             *            S  *A              *            BX                                                   *
11*     P                        *            S  *A              *            B                                                    *
12* P                            *             S *A              *            B X                                                  *
13*   P                          *             S *A              *            B   X                                                *
14*P                             *             S *              A*            B    X                                               *
15*P                             *             S *A              *            B     X                                              *
16*P                             *             S *A              *            B   X                                                *
17*P                             *             S *A              *            B   X                                                *
18*P                             *             S *A              *            B  X                                                 *
19* P                            *             S *A              *            B  X                                                 *
20*                 P            *              S*A              *            B          X   R                                     *
21*P                             *              S*A              *            B                                R   X               *
22*P                             *              S*A              *            B                                    R  X            *
23*   P                          *              S*A              *            B               R               X                    *
24*P                             *              S*A              *            B            R           X                           *
25*P                             *              S*A              *            B           R        X                               *
26*P                             *              S*A              *            B         R       X                                  *
27*P                             *              S*A              *            B         R     X                                    *
28*P                             *              S*A              *            B         R X                                        *
29*P                             *              S*A              *            B        R                                           *
30*P                             *              S*A              *            B    X  R                                            *
  0-------------*---------------* --------------*---------------* ---*---*---*---*---*---*---*---*---*---*---*---*---*---*---*---*
                25            50              30                5    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16
            P/DIP/EMT                 SASM            AET                                    FLEXSCALE
              (MM)                    (CM)             (MM)                                FLOWS (CM/S)
```

```
                              ** HYDROLOGIC MODEL/CALIBRATION-STREAMFLOW SIMULATION **

                                         BASIN: NITH RIVER                          GAUGE: 10

                              OPTION: EIGHT PLOT CALIBRATION/SIMULATION OUTPUT(SNOWMELT)

                                         WATER-YEAR: 1974 TO 1974        MONTH: 11

  1*D                                                 *X                   *W                                                  *
  2*D                                                 *X                   *W                                                  *
  3*D                                                 *X                   *W                                                  *
  4*D                                                 *X                   *W                                                  *
  5*D                                                 *X                   *W                                                  *
  6*D                                                 *X                   *W                                                  *
  7*D                                                 *X                   *W                                                  *
  8*D                                                 *X                   *W                                                  *
  9*D                                                 *X                   *W                                                  *
 10*D                                                 *X                   *W                                                  *
 11*D                                                 *X                   *W                                                  *
 12*D                                                 *X                   *W                                                  *
 13*D                                                 *X                   *W                                                  *
 14*D                                                 *X                   *W                                                  *
 15*D                                                 *X                   *W                                                  *
 16*D                                                 *X                   *W                                                  *
 17*D                                                 *X                   *W                                                  *
 18*D                                                 *X                   *W                                                  *
 19*D                                                 *X                   *W                                                  *
 20*D                                                 *X                   *W                                                  *
 21*D                                                 *X                   *W                                                  *
 22*D                                                 *X                   *W                                                  *
 23*D                                                 *X                   *W                                                  *
 24*D                                                 *X                   *W                                                  *
 25*D                                                 * X                  *W                                                  *
 26*D                                                 * X                  *W                                                  *
 27*D                                                 *X                   *W                                                  *
 28*D                                                 *X                   *W                                                  *
 29*D                                                 *X                   *W                                                  *
 30*D                                                 *X                   *W                                                  *
   *----*----*----*----*----*----*----*----*----*----* ---*----*----*----*  ----*----*----*----*----*----*----*----*----*----*
   0   15   30   45   60   75   90  105  120  135  150  .25  .5  .75 1.0   50  100  150  200  250  300  350  400  450  500
                          DEP1                                DEN1                                WEQ1
                          (CM)                              (G/CM**3)                             (MM)


     OUTPUT FOR INTERCEPTION STORAGE FOR SNOWMELT ROUTINE           JULIAN DATE = 336
    PR =   2547. SNOW =  10189. DEP1 =    0.38 DEN1 = 0.1000 TEM1 =  23.99
    PN =   2038. SNOWN =   9680. AEIS =    162. MIST =      0. VIS =    856.

     OUTPUT FROM SNOWMELT ROUTINE
    AESP = -.0006 DEP1 =  0.386 TEM1 =     32. MT = 0.1200 EMT = 0.0094 DEN1 = 0.0963 PR =   2399. WC1 = 0.0330
    DTP=   2399. WEQ1 =  0.0372


     OUTPUT FOR INTERCEPTION STORAGE FOR SNOWMELT ROUTINE           JULIAN DATE = 337
    PR =      0. SNOW =   2547. DEP1 =    0.48 DEN1 = 0.0964 TEM1 =   3.11
    PN =      0. SNOWN =   2385. AEIS =   1018. MIST =      0. VIS =      0.
```

```
                                                       WATERSHED/STREAM FLOW SIMULATION
                              OPTION 9 - PLOTS OF PRECIPITATION (P), CALCULATED RUNOFF (R) AND OBSERVED RUNOFF (*)
               WATER-YEAR: 1974 TO 1974        MONTH: 11        BASIN: NITH RIVER              GAUGE: 10

  DAY                          PRECIPITATION                  --------                      RUNOFF
     **************************************************************************************************************************
   1   P                                                                                    *R
   2 P                                                                                     * R
   3                                                                                       * R                       P
   4                               P                                                         R  *
   5                                                                                         R     *                          P
   6          P                                                                              R      *
   7 P                                                                                       R       *
   8 P                                                                                       R       *
   9 P                                                                                       R     *
  10 P                                                                                       R   *
  11                                                                                         R *                              P
  12                                                              P                          R     *
  13                                                                                         R          *      P
  14                    P                                                                    R            *
  15                                      P                                                  R            *
  16                           P                                                             R         *
  17          P                                                                              R        *
  18 P                                                                                       R       *
  19                                                              P                          R       *
  20                                                                                                                   *       R
  21             P                                                                                                             *
  22 P                                                                                                                         *
  23                                                                                                   P                       *
  24                               P                                                                                        R  *
  25        P                                                                                                           R      *
  26           P                                                                                                     R         *
  27                                          P                                                                     R          *
  28                                        P                                                                        R   *
  29 P                                                                                                            * R
  30 P                                                                                                   *     R
```

```
                                   ** WATERSHED/STREAMFLOW SIMULATION **

                                      BASIN: NITH RIVER                          GAUGE: 10

                                    OPTION: TEN   MODEL PARAMETERS: SUMMARY

    * DRAINAGE AREAS/INTERCEPTION & DEPRESSION MAX. STORAGE
      AREA=              254720.00 (AC)   103081.50 (HA)
      ISCM/FARIS               0.02 (IN)          0.05 (CM) /          0.20 (IN)          0.51(CM)
      DSCM/FARDS               0.50 (IN)          1.27 (CM) /          0.05 (IN)          0.13(CM)

    *
    * SOIL HYDROLOGIC PARAMETERS - POROSITY/WILTING POINT/FIELD CAPACITY
            STEADY-STATE INFILTRATION RATE/SATURATED PERMEABILITY

                            LAYER 1                                   LAYER 2                                        LAYER 3
      TS   =  4850429.00 (AC-IN)        48.37 (CM)
      WP   =   357627.00 (AC-IN)         3.57 (CM)    357627.00 (AC-IN)         3.57 (CM)    357627.00 (AC-IN)         3.57 (CM)
      FCAP=  1019695.00 (AC-IN)         10.17 (CM)   1019695.00 (AC-IN)        10.17 (CM)   1019695.00 (AC-IN)        10.17 (CM)
      FINC=         0.04 (IN/HR)         1.02 (MM/HR)
      SHC =         0.04 (IN/HR)         1.02 (MM/HR)

    * GROUNDWATER FLOW INDICES - TRANSMISSIVITY/COEFFICIENT OF STORAGE /
                    INDEX OF FLOW GRADIENT
      TRANS =    0.004000 (IN/DY)    0.096000 (MM/DY)
      CS    =    0.049000
      ALARGL=   485232.00 (FT)       147898.69 (M)
      ALITL =    11433.10 (FT)         3484.81 (M)
      HMIN  =      100.00 (FT)           30.48 (M)

    * LTSM - LONG-TERM-STEP-MODEL PARAMETERS

      OPTIMIZED                                                     CONSTANTS
      CP   =          2.80 (IN/DY)         71.12 (MM/DY)
      FINC=           0.96 (IN/DY)         24.38 (MM/DY)       B  =          1.30
      SHC  =          0.96 (IN/DY)         24.38 (MM/DY)       K1=           3.22 DAYS
      EP   =          0.45                                      K2=           5.08 DAYS
      EM   =          0.40                                      K3=           8.99 DAYS
      C1   =          0.29
      CS   =         0.049
     TRANS=          0.004 (MM/HR)

    * STSM - SHORT-TERM-STEP-MODEL PARAMETERS

      OPTIMIZED                                                     CONSTANTS
      A    =          0.30 (IN/HR)          7.62 (MM/HR)       C1=           0.29
      AN   =          1.40                                      B  =          1.30
      AL   =          0.41                                      K1=          77.21 HRS
      NN   =          1.72                                      K2=         121.81 HRS
      FINC=           0.96 (IN/DY)         24.36 (MM/DY)
      SHC =           0.96 (IN/DY)         24.36 (MM/DY)       K3=         215.65 HRS

      TARHIST (M)=         0.00 /          0.00 /          0.01 /          0.01 /          0.01 /          0.02 /          0.01 /          0.01 /
                                 0.01 /          0.00 /          0.01 /

    * SNMELT - SNOWMELT MODEL

      DENSITY-DEPTH INDICES    MELT INDICES
      AAP   =        0.484      BS=       0.1000
      BAP   =       -0.180      B1=       0.0120
      ARAP  =        0.492      B2=       0.0040
      BRAP  =       -0.185      BF=       1.1000
      AMP   =        0.751
```

```
   BRMP =        -0.258
   BRAP1=        -0.001
   BRMP1=         0.003

 * INTIALIZATION INDICES

   SOIL MOISTURE                INITIAL              END OF PERIOD
     ANTSM(LAYER 1)             7.98 (CM)            10.17 (CM)
     ANTSM(LAYER 2)             8.97 (CM)            10.17 (CM)
     ANTSM(LAYER 3)             9.97 (CM)            10.17 (CM)

   INTERFLOW
     RIFL =                     0.0      (MM/DY)       0.1105 (MM/DY)

   SURFACE FLOW
     RSRO =                     0.0      (MM/DY)       0.0      (MM/DY)

   BASEFLOW
     MACT =                     104.24 (M)             105.36 (M)
     RBF  =                     0.0      (MM/DY)       0.2803 (MM/DY)

 * INTERCEPTION/DEPRESSION

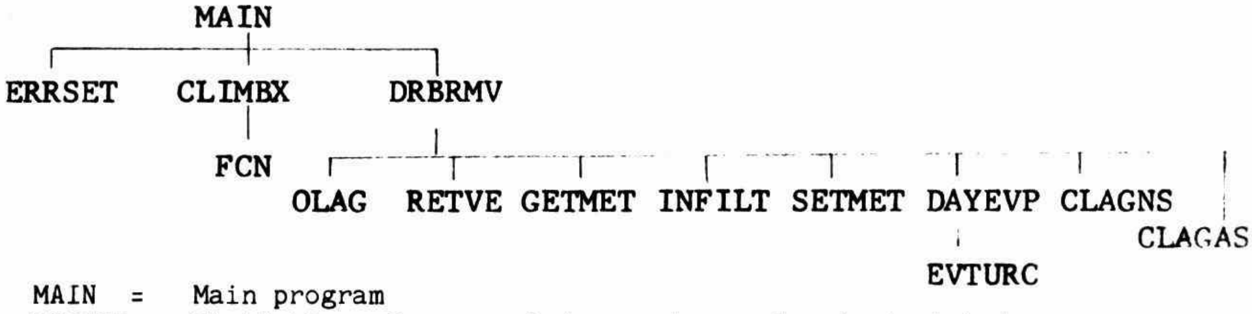

     VIS  =                     0.0      (MM)          0.0      (MM)
    MIST  =                     0.0      (MM)          0.0      (MM)
    VDS   =                     0.0      (MM)          0.0000 (MM)
```

APPENDIX B

SQGRID MODEL

APPENDIX B - SQGRID Model

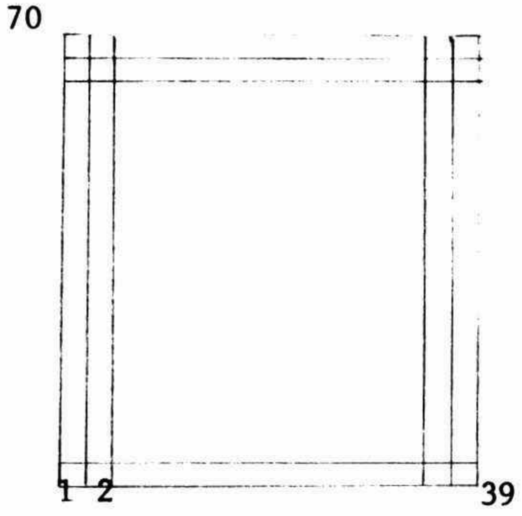
(i) Structure of the Computer Program



MAIN = Main program
ERRSET= Statistics of errors between observed and simulated flows
DRBRMV= Runoff model
FCN = Optimizing function
GETMET= Extract (reformat) meteorological data
CLIMBX= "hill-climbing" optimization routine
OLAG = Computes overland lag (in hours)
RETVE = Reads records from basin file
INFILT= Computes infiltration from surface into soil, and percolation from soil to ground water storage
SETMET= Reads temperature and precipitation data
DAYEVP= Calculates daily evaporation
EVTURC= Calculates annual evaporation using Turc's formula
CLAGNS= Computes channel lag (in hours) for natural conditions
CLAGAS= Computes channel lag (in hours) for artificial conditions

(ii) Basin File (BASFI)

The Basin File (BASFI) is a direct access file containing 33 records of 2730 half word integers for the 2730, 2 x 2 km grid cells in the study area. Each record represents a particular physical characteristic of the study area. Data in the file are stored by column, from bottom to top and from left to right. The Grand River above Paris is represented by a 39 x 70 matrix, or 2730 cells.



Layout of the File

Record	Contents
1	Header (title)
2	Direction of flow (1=north, 2=east, 3=south, 4=west, 0=not in study area)
3	[illegible]
4	Number of squares water has flowed through to this square
5	Percentage of infiltration capacity: $\sum_{j=1}^{\text{total \# land uses}} (L_i * \% \text{ land use } i) * 100$ where L_i represents the infiltration capacity of land i
6	Maximum voids in soil (%) $\sum_{j=1}^{\# \text{ of soil types}} (S_j * \% \text{ soil } j \text{ in grid}) * 100$ (80% of this figure is the maximum soil moisture available for evaporation)
7	Constant rate of infiltration after prolonged wetting (inches/hour * 1000)
8	Percentage of soil Type 1 - till moraine
9	Percentage of soil Type 2 - till plain
10	Percentage of soil Type 3 - clay plain
11	Percentage of soil Type 4 - sand plain
12	Percentage of soil Type 5 - limestone plain
13	Percentage of soil Type 6 - swamp and bog
14	Percentage of soil Type 7 - kame moraine
15	Percentage of soil Type 8 - water
16	Percentage of soil Type 9 - Canadian Shield
17	Percentage of soil Type 10- Niagara Escarpment
18	Percentage of land use Type 1 - industrial
19	Percentage of land use Type 2 - residential
20	Percentage of land use Type 3 - associated urban
21	Percentage of land use Type 4 - horticulture
22	Percentage of land use Type 5 - orchard and vinyards
23	Percentage of laud use Type 6 - hay, grain and soybeans
24	Percentage of land use Type 7 - tobacco
25	Percentage of land use Type 8 - improved pasture
26	Percentage of land use Type 9 - open and scrub grassland

Record	Contents
27	Percentage of land use Type 10 - unproductive land
28	Percentage of land use Type 11 - dense woodland
29	Percentage of land use Type 12 - open woodland
30	Percentage of land use Type 13 - scrub woodland
31	Percentage of land use Type 14 - cut over burnt over woodland
32	Percentage of land use Type 15 - swamp and marsh
33	Percentage of land use Type 16 - lakes and rivers

(iii) Program BASFIA

Purpose

Creation of four records of a direct access basin file, determination of the hierarchial order and establishment of the drainage basin, using "manually defined" flow directions.

Preparation of Input for BASFIA

(a) Choice of suitable grid size:

The grid size refers to the length of one side of a grid element on the earth's surface. There are several criteria to determine the size of the grid.

1. Level of detail available in information (i.e. the scale of topographic maps, soil maps, land use maps, etc.).

General Guide:

Scale	Grid Size
1:50,000	5-10 km
1:25,000	1-2 km

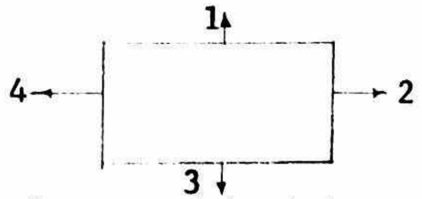
2. Required level of detail in simulation - The purpose of the study must be considered. A smaller grid size gives a higher degree of accuracy.

3. Financial constraints - The time, budget, and capability of the computer system are important. Decreasing the grid size by half could increase work load, CPU time, core requirements and disk storeage by four to six times.

(b) Establish grid system and direction of flow:

On a small scale topographic map, the boundary of the river basin and the direction of flow for each grid is usally well defined by the channel network and elevation.

Flows are coded as follows:



0 = not in study area
1 = flow to north
2 = flow to east
3 = flow to south
4 = flow to west

(iv) Program BASFIB

Purpose

To overlay digitized spatially distributed data on soil types and land use to the basin file.

Preparation of Input:

Digitizing and editing - digitize the land use/land cover map or the soil map covering the study area. Edit the digitized data and create a VBS file to store the edited data as follows:

ICODE, NPTS, NPOL, (X(I), Y(I), I=1, NPTS)

where ICODE= code of land use or soil (i.e. the record number in the basin file)

NPTS = number of digitized points in particular polygon

NPOL = sequence number of the polygon

X(I), Y(I) = Co-ordinates of the vertex of the polygon

(v) Program BASFIC

Purpose:

Delineation of a sub-basin above any given point on the 39 x 70 matrix which defines the Grand River study area.

Input:

Unit 5

ICOUT = column number of the "mouth" of the sub-basin being considered (a number from 1-39)

JROUT = row number of the "mouth" of the sub-basin (a number from 1-70)

(vi) Program BASFID

Purpose:

To generate both digital and gray maps showing the spatial distribution of data in the basin file (eg. soil, land use data)

Input:

One card is input for each set of maps required. The card adopts the following format:

ISOIL, TITLE (format: 12, 8A8)

ISOIL = record number which is used to store desired spatially distributed data (e.g. 8 = till moraine, 21 = horticultural land use)

TITLE = title or name of record

(vii) Program BASFIE

Purpose:

To calculate the following information, using soil, land use, and land-cover distribution.

a - principal land use (record 5 of basin file)
b - maximum soil moisture available for evaporation (record 6 of basin file):80% of maximum voids in soil = maximum soil moisture available for evaporation
c - constant rate of infiltration after prolonged wetting (record 7 of basin file)

Input:

Input from basin file only: no card image input required.

(viii) Input Parameters and Variables

Card No.	Format	Contents
1	20A4	Title
2	10F5.0	SAINIT, FCFRAC, GWFRAC, GWINIT, GWLAG, SFOLAG, SOILT, SNOWT, TIMEIN
3	8I5	NSQ, INYR, INMTH, INDAY INDAYS, MASDIV, IOPT, NPRIME
4	2I5	NIRIPV, NVAR

5	4F10.0	G(I), I=1, NVAR
6	4F10.0	H(I), I=1, NVAR
7	2I5	NLOOK, LOOKSQ
8-n	2I4	NREC, NXISQ
n-end	6F10.0	QMESD

SAINIT = Initial available soil moisture storage
FCFRAC = Infiltration scaling factor
GWFRAC = Fraction of ground water flow to base flow
SFCLAG = Travel time of channel flow scaling factor
GWINIT = Initial ground water storage
GLWAG = Travel time for ground water flow
SFOLAG = Overland flow travel time scaling factor
SOILT = Soil thickness
SNOWT = Snow thickness
TIMEIN = Basic time interval
NSQ = Number of squares in sub-basin
INYR,INMTH,INDAY
= beginning year, month, day of simulation
INDAYS = Number of days in simulation
MAXDIV = Subdivisions of TIMEIN
IOPT = Set to 1 for CLIMBX optimization
NPRIME = 999 for brief output
NIRIPV = Number of trials in CLIMBX
NVAR = Number of model parameters being optimized
G = Lower bounds of model parameters being optimized
H = Upper bounds of model parameters being optimized
NLOOK = Number of squares for which detailed output is required
LOOKSQ = Subscript number of the squares for which detailed output is required
NREC = Location in basin file record of each square
NXISQ = Number of square water flows to from each square
QMESD = Hourly flow data

```
DETAILED RESULTS FOR SQUARE     74

 ITR DAY HR DV PREC        TEMP  EVAP       SFSTOR SFINC1 OVLAG CHLAG SFOUTA   INF        SA1      DTFC          GWINC1     GWSTOR      GWOUTA
                IN.        D FAR IN.        IN.    IN.    HR.   HR.   IN/HR    IN.        IN.      IN.           IN.        IN.         IN/HR
---------------------------------------------------------------------------------------------------------------------------------------
 145  7  1  1 0.0         59.00 0.00040   0.592 0.22250  8.11  2.53 0.23614 0.0       31.79842 0.0         0.1009E 01 0.6866E 02 0.8744E 00
 146  7  2  1 0.0         57.00 0.00039   0.578 0.21901  8.11  2.55 0.23182 0.0       31.79880 0.0         0.1009E 01 0.6881E 02 0.8753E 00
 147  7  3  1 0.0         56.00 0.00039   0.566 0.21575  8.12  2.56 0.22779 0.0       31.79918 0.0         0.1010E 01 0.6895E 02 0.8762E 00
 148  7  4  1 0.0         56.00 0.00039   0.554 0.21271  8.13  2.58 0.22403 0.0       31.79956 0.0         0.1010E 01 0.6908E 02 0.8770E 00
 149  7  5  1 0.0         55.00 0.00039   0.544 0.20987  8.13  2.59 0.22052 0.0       31.79994 0.0         0.1010E 01 0.6921E 02 0.8779E 00
 150  7  6  1 0.0         55.00 0.00039   0.533 0.20719  8.14  2.60 0.21725 0.0       31.80032 0.0         0.1011E 01 0.6934E 02 0.8788E 00
 151  7  7  1 0.0         58.00 0.00039   0.524 0.20466  8.15  2.61 0.21417 0.0       31.80070 0.0         0.1011E 01 0.6948E 02 0.8797E 00
 152  7  8  1 0.0         61.00 0.00038   0.515 0.20225  8.15  2.62 0.21129 0.0       31.80109 0.0         0.1012E 01 0.6961E 02 0.8806E 00
 153  7  9  1 0.0         66.00 0.00038   0.506 0.19997  8.16  2.64 0.20857 0.0       31.80147 0.0         0.1012E 01 0.6974E 02 0.8814E 00
 154  7 10  1 0.0         68.00 0.00038   0.498 0.19778  8.16  2.65 0.20600 0.0       31.80185 0.0         0.1012E 01 0.6987E 02 0.8823E 00
 155  7 11  1 0.0         71.00 0.00038   0.490 0.19567  8.17  2.66 0.20355 0.0       31.80222 0.0         0.1013E 01 0.7000E 02 0.8832E 00
 156  7 12  1 0.0         73.00 0.00038   0.483 0.19364  8.17  2.67 0.20123 0.0       31.80258 0.0         0.1013E 01 0.7013E 02 0.8840E 00
 157  7 13  1 0.0         74.00 0.00038   0.476 0.19166  8.18  2.68 0.19900 0.0       31.80295 0.0         0.1014E 01 0.7026E 02 0.8849E 00
 158  7 14  1 0.0         76.00 0.00038   0.469 0.18974  8.18  2.69 0.19687 0.0       31.80331 0.0         0.1014E 01 0.7039E 02 0.8857E 00
 159  7 15  1 0.0         78.00 0.00038   0.462 0.18786  8.19  2.70 0.19481 0.0       31.80368 0.0         0.1015E 01 0.7052E 02 0.8866E 00
 160  7 16  1 0.0         77.00 0.00037   0.456 0.18601  8.19  2.70 0.19281 0.0       31.80405 0.0         0.1015E 01 0.7064E 02 0.8874E 00
 161  7 17  1 0.0         77.00 0.00037   0.450 0.18419  8.20  2.71 0.19086 0.0       31.80441 0.0         0.1015E 01 0.7077E 02 0.8883E 00
 162  7 18  1 0.0         78.00 0.00037   0.444 0.18239  8.20  2.72 0.18897 0.0       31.80478 0.0         0.1016E 01 0.7090E 02 0.8891E 00
 163  7 19  1 0.0         77.00 0.00037   0.438 0.18059  8.21  2.73 0.18711 0.0       31.80515 0.0         0.1016E 01 0.7103E 02 0.8900E 00
 164  7 20  1 0.0         75.00 0.00037   0.432 0.17881  8.21  2.74 0.18527 0.0       31.80551 0.0         0.1016E 01 0.7115E 02 0.8908E 00
 165  7 21  1 0.0         72.00 0.00037   0.426 0.17702  8.22  2.75 0.18346 0.0       31.80588 0.0         0.1017E 01 0.7128E 02 0.8916E 00
 166  7 22  1 0.0         68.00 0.00037   0.420 0.17523  8.22  2.76 0.18167 0.0       31.80624 0.0         0.1017E 01 0.7140E 02 0.8925E 00
 167  7 23  1 0.0         66.00 0.00037   0.414 0.17344  8.23  2.77 0.17988 0.0       31.80661 0.0         0.1018E 01 0.7153E 02 0.8933E 00
 168  7 24  1 0.0         64.00 0.00037   0.408 0.17163  8.23  2.78 0.17810 0.0       31.80698 0.0         0.1018E 01 0.7165E 02 0.8941E 00

QLOOK(1,  7) =     4.86115 INCHES

 169  8  1  1 0.0         62.00 0.00037   0.403 0.16981  8.24  2.79 0.17632 0.0       31.80734 0.0         0.1018E 01 0.7178E 02 0.8950E 00
 170  8  2  1 0.0         61.00 0.00037   0.397 0.16798  8.24  2.80 0.17454 0.0       31.80771 0.0         0.1019E 01 0.7190E 02 0.8958E 00
 171  8  3  1 0.0         60.00 0.00036   0.391 0.16612  8.25  2.82 0.17274 0.0       31.80806 0.0         0.1019E 01 0.7202E 02 0.8966E 00
 172  8  4  1 0.0         58.00 0.00036   0.385 0.16425  8.25  2.83 0.17094 0.0       31.80841 0.0         0.1019E 01 0.7214E 02 0.8974E 00
 173  8  5  1 0.0         58.00 0.00036   0.379 0.16235  8.26  2.84 0.16913 0.0       31.80876 0.0         0.1020E 01 0.7227E 02 0.8982E 00
 174  8  6  1 0.0         58.00 0.00036   0.373 0.16043  8.27  2.85 0.16730 0.0       31.80911 0.0         0.1020E 01 0.7239E 02 0.8990E 00
 175  8  7  1 0.0         61.00 0.00036   0.366 0.15850  8.27  2.86 0.16545 0.0       31.80946 0.0         0.1020E 01 0.7251E 02 0.8998E 00
 176  8  8  1 0.0         64.00 0.00036   0.360 0.15654  8.28  2.88 0.16359 0.0       31.80981 0.0         0.1021E 01 0.7263E 02 0.9006E 00
 177  8  9  1 0.0         68.00 0.00036   0.354 0.15457  8.28  2.89 0.16171 0.0       31.81017 0.0         0.1021E 01 0.7275E 02 0.9014E 00
 178  8 10  1 0.0         71.00 0.00036   0.347 0.15258  8.29  2.90 0.15982 0.0       31.81052 0.0         0.1022E 01 0.7287E 02 0.9022E 00
 179  8 11  1 0.0         73.00 0.00036   0.341 0.15059  8.30  2.91 0.15790 0.0       31.81087 0.0         0.1022E 01 0.7299E 02 0.9030E 00
 180  8 12  1 0.0         74.00 0.00036   0.334 0.14858  8.30  2.93 0.15598 0.0       31.81122 0.0         0.1022E 01 0.7311E 02 0.9038E 00
 181  8 13  1 0.0         76.00 0.00035   0.328 0.14658  8.31  2.94 0.15405 0.0       31.81157 0.0         0.1022E 01 0.7323E 02 0.9046E 00
 182  8 14  1 0.0         77.00 0.00035   0.321 0.14457  8.32  2.96 0.15210 0.0       31.81192 0.0         0.1023E 01 0.7334E 02 0.9054E 00
 183  8 15  1 0.0         78.00 0.00035   0.314 0.14256  8.33  2.97 0.15015 0.0       31.81227 0.0         0.1023E 01 0.7346E 02 0.9062E 00
 184  8 16  1 0.0         79.00 0.00035   0.307 0.14056  8.33  2.99 0.14820 0.0       31.81262 0.0         0.1023E 01 0.7358E 02 0.9069E 00
 185  8 17  1 0.0         78.00 0.00035   0.301 0.13857  8.34  3.00 0.14624 0.0       31.81297 0.0         0.1024E 01 0.7369E 02 0.9077E 00
 186  8 18  1 0.0         78.00 0.00035   0.294 0.13658  8.35  3.02 0.14429 0.0       31.81331 0.0         0.1024E 01 0.7381E 02 0.9085E 00
 187  8 19  1 0.0         78.00 0.00035   0.287 0.13462  8.36  3.03 0.14235 0.0       31.81364 0.0         0.1024E 01 0.7393E 02 0.9092E 00
 188  8 20  1 0.0         74.00 0.00035   0.280 0.13266  8.36  3.05 0.14041 0.0       31.81398 0.0         0.1025E 01 0.7404E 02 0.9100E 00
 189  8 21  1 0.0         71.00 0.00035   0.273 0.13073  8.37  3.06 0.13848 0.0       31.81432 0.0         0.1025E 01 0.7416E 02 0.9108E 00
 190  8 22  1 0.0         69.00 0.00035   0.266 0.12881  8.38  3.08 0.13656 0.0       31.81465 0.0         0.1025E 01 0.7427E 02 0.9115E 00
 191  8 23  1 0.0         67.00 0.00034   0.259 0.12692  8.39  3.10 0.13466 0.0       31.81499 0.0         0.1025E 01 0.7438E 02 0.9123E 00
 192  8 24  1 0.0         65.00 0.00034   0.253 0.12505  8.40  3.11 0.13278 0.0       31.81532 0.0         0.1026E 01 0.7450E 02 0.9130E 00

QLOOK(1,  8) =     3.71568 INCHES
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APPENDIX C

TVA MODEL

APPENDIX C - TVA Model

MODEL PARAMETERS AND CONSTANTS

Primary Model Parameters

B = a volumetric parameter used to preserve mass balance
A = a surface runoff volume parameter for winter storms
D = a surface runoff volume parameter for summer storms
GWK = a ground water volumetric parameter
TDSRO= a routing parameter

Secondary Model Parameters That May Be Optimized

SROK = a surface runoff recession constant
GWMIN= a threshold constant used in allocating ground water
BHORP= soil B horizon permeability
GROKW= an interflow or winter recession constant
GROKS= a summer ground water routing contant

Model Constants

ACREIN= drainage area in square miles
WCEPT = winter interception capacity
SCEPT = summer interception capacity
AHORD = moisture capacity in the soil A horizon
GWDOR = a ground water reservoir allocation constant
FALL,WINTER,SPRING, SUMMER = day of the year for the beginning of the respective season

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                             PATTERN SEARCH FOR OPTIMUM OF OBJECTIVE FUNCTION
                             ERAMOSA RIVER STREAMFLOW SIMULATION 1972 (TEST ONLY, NO OPTIMIZATION)
                          IOPT=  1    OPTIMIZE ON THE FOLLOWING
                 1=SSE      2=WEIGHTED SSE      3=SUM OF ABSOLUTE ERRORS      4=SUM OF PREDICTIONS
PRECIP LEAD IN NDY=          31
PRECIP LEAD IN NDY=          31
PRECIP LEAD IN NDY=          30
LEAD IN PRECIP NN=             32
PRECIP DATA NN=        366
C NN=          366

RAINFALL FOR YEAR 1972             ERAMOSA RIVER STREAMFLOW SIMULATION 1972 (TEST ONLY, NO OPTIMIZATION)         ANALYSIS

DAY    OCT.       NOV.       DEC.       JAN.       FEB.       MAR.       APR.       MAY        JUNE       JULY       AUG.       SEPT.     DAY

  1  0.0        0.0        0.0        0.0        0.0        0.1260 01  0.1600 00  0.4700 00  0.1100 00  0.0        0.2800 00  0.0          1
  2  0.0        0.5000-01  0.0        0.0        0.0        0.0        0.0        0.9000-01  0.0        0.3100 00  0.1800 00  0.1700 00    2
  3  0.0        0.1700 00  0.0        0.0        0.0        0.0        0.0        0.0        0.2900 00  0.1100 00  0.0        0.0          3
  4  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0          4
  5  0.1000-01  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.3000-01    5
  6  0.5000-01  0.1700 00  0.3800 00  0.0        0.0        0.0        0.0        0.1300 00  0.0        0.0        0.4000 00  0.0          6
  7  0.0        0.0        0.1400 00  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.1500 00  0.8000 00    7
  8  0.2900 00  0.0        0.1700 00  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.1900 00  0.7000-01    8
  9  0.1700 00  0.0        0.4100 00  0.0        0.0        0.0        0.0        0.0        0.0        0.1000-01  0.0        0.0          9
 10  0.0        0.1800 00  0.7400 00  0.0        0.0        0.0        0.1300 00  0.0        0.0        0.0        0.0        0.0         10
 11  0.0        0.2000-01  0.0        0.0        0.0        0.0        0.3700 00  0.0        0.0        0.0        0.5000-01  0.0         11
 12  0.0        0.9000-01  0.0        0.0        0.0        0.1000 00  0.9600 00  0.0        0.0        0.0        0.0        0.0         12
 13  0.1800 00  0.0        0.0        0.0        0.0        0.0        0.4000 00  0.3300 00  0.0        0.6200 00  0.0        0.1600 00   13
 14  0.0        0.1300 00  0.0        0.0        0.0        0.0        0.5700 00  0.7100 00  0.0        0.3400 00  0.2200 00  0.0         14
 15  0.0        0.0        0.7800 00  0.0        0.0        0.6000-01  0.3700 00  0.4500 00  0.1000-01  0.1300 00  0.0        0.0         15
 16  0.0        0.0        0.4000 00  0.0        0.0        0.0        0.9000 00  0.8000-01  0.0        0.0        0.1700 00  0.0         16
 17  0.0        0.0        0.0        0.0        0.0        0.4000-01  0.4100 00  0.0        0.0        0.0        0.2000-01  0.0         17
 18  0.0        0.2500 00  0.0        0.9000-01  0.0        0.0        0.8900 00  0.0        0.0        0.1700 00  0.0        0.1200 00   18
 19  0.0        0.1000-01  0.0        0.0        0.0        0.0        0.1030 01  0.0        0.0        0.0        0.0        0.0         19
 20  0.0        0.1400 00  0.0        0.0        0.0        0.0        0.5600 00  0.0        0.1100 00  0.0        0.0        0.0         20
 21  0.0        0.0        0.0        0.0        0.0        0.5400 00  0.4800 00  0.0        0.1320 01  0.0        0.0        0.2000-01   21
 22  0.3200 00  0.0        0.0        0.0        0.0        0.5000 00  0.5100 00  0.0        0.5100 00  0.0        0.0        0.0         22
 23  0.0        0.0        0.0        0.0        0.0        0.0        0.3500 00  0.0        0.5900 00  0.9000-01  0.1200 00  0.7000-01   23
 24  0.4000 00  0.0        0.2000 00  0.2500 00  0.0        0.0        0.3000 00  0.0        0.4000-01  0.3800 00  0.0        0.1000-01   24
 25  0.0        0.0        0.0        0.0        0.0        0.0        0.2300 00  0.0        0.0        0.0        0.0        0.4700 00   25
 26  0.0        0.1200 00  0.0        0.0        0.0        0.0        0.1000-01  0.0        0.0        0.0        0.4000-01  0.3000 00   26
 27  0.0        0.3600 00  0.8000-01  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.5100-01  0.0         27
 28  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.1000-01   28
 29  0.0        0.0        0.0        0.0        0.1500 00  0.0        0.0        0.1000-01  0.8200 00  0.0        0.0        0.9900 00   29
 30  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.5500 00  0.1900 00  0.0        0.0        0.0         30
 31  0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.7600 00  0.0        0.0        0.0        0.0         31

TOTAL 0.1420 01 0.1690 01 0.3300 01 0.3400 00 0.1500 00 0.2500 01 0.8630 01 0.3580 01 0.3990 01 0.2160 01 0.1870 01 0.3220 01

         TOTAL FOR WATER YEAR = 0.3285D 02
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65

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                                    TENNESSEE VALLEY AUTHORITY ---- CONTINUOUS DAILY-STREAMFLOW MODEL

 OBSERVED RUNOFF FOR YEAR 1972                       ERAMOSA RIVER STREAMFLOW SIMULATION 1972 (TEST ONLY, NO OPTIMIZATION)              ANALYSIS
 DAY     OCT.       NOV.       DEC.       JAN.       FEB.       MAR.       APR.       MAY        JUNE       JULY       AUG.       SEPT.    DAY

   1  0.921D-02  0.132D-01  0.171D-01  0.204D-01  0.196D-01  0.213D-01  0.417D-01  0.650D-01  0.531D-01  0.491D-01  0.997D-02  0.973D-02    1
   2  0.891D-02  0.121D-01  0.168D-01  0.241D-01  0.192D-01  0.215D-01  0.425D-01  0.728D-01  0.699D-01  0.486D-01  0.122D-01  0.973D-02    2
   3  0.924D-02  0.110D-01  0.135D-01  0.213D-01  0.196D-01  0.241D-01  0.417D-01  0.813D-01  0.666D-01  0.405D-01  0.128D-01  0.117D-01    3
   4  0.969D-02  0.112D-01  0.124D-01  0.200D-01  0.217D-01  0.286D-01  0.478D-01  0.830D-01  0.486D-01  0.367D-01  0.127D-01  0.111D-01    4
   5  0.871D-02  0.114D-01  0.125D-01  0.194D-01  0.221D-01  0.290D-01  0.499D-01  0.760D-01  0.421D-01  0.330D-01  0.110D-01  0.989D-02    5
   6  0.854D-02  0.113D-01  0.148D-01  0.192D-01  0.217D-01  0.307D-01  0.495D-01  0.650D-01  0.366D-01  0.251D-01  0.114D-01  0.119D-01    6
   7  0.834D-02  0.127D-01  0.214D-01  0.204D-01  0.213D-01  0.266D-01  0.421D-01  0.609D-01  0.287D-01  0.213D-01  0.166D-01  0.106D-01    7
   8  0.850D-02  0.134D-01  0.315D-01  0.213D-01  0.211D-01  0.270D-01  0.468D-01  0.546D-01  0.229D-01  0.184D-01  0.175D-01  0.161D-01    8
   9  0.924D-02  0.133D-01  0.324D-01  0.221D-01  0.208D-01  0.266D-01  0.461D-01  0.523D-01  0.215D-01  0.168D-01  0.137D-01  0.167D-01    9
  10  0.112D-01  0.140D-01  0.450D-01  0.215D-01  0.208D-01  0.242D-01  0.441D-01  0.466D-01  0.196D-01  0.157D-01  0.164D-01  0.143D-01   10
  11  0.146D-01  0.159D-01  0.654D-01  0.211D-01  0.206D-01  0.278D-01  0.621D-01  0.408D-01  0.173D-01  0.145D-01  0.141D-01  0.121D-01   11
  12  0.142D-01  0.166D-01  0.764D-01  0.206D-01  0.206D-01  0.255D-01  0.108D 00  0.385D-01  0.166D-01  0.154D-01  0.123D-01  0.107D-01   12
  13  0.122D-01  0.172D-01  0.568D-01  0.200D-01  0.208D-01  0.249D-01  0.202D 00  0.334D-01  0.168D-01  0.139D-01  0.110D-01  0.109D-01   13
  14  0.113D-01  0.151D-01  0.373D-01  0.197D-01  0.211D-01  0.247D-01  0.353D 00  0.381D-01  0.175D-01  0.176D-01  0.118D-01  0.114D-01   14
  15  0.117D-01  0.183D-01  0.372D-01  0.202D-01  0.213D-01  0.245D-01  0.454D 00  0.536D-01  0.172D-01  0.357D-01  0.121D-01  0.948D-02   15
  16  0.119D-01  0.182D-01  0.687D-01  0.208D-01  0.217D-01  0.245D-01  0.413D 00  0.785D-01  0.164D-01  0.609D-01  0.104D-01  0.756D-02   16
  17  0.113D-01  0.157D-01  0.846D-01  0.217D-01  0.221D-01  0.262D-01  0.437D 00  0.862D-01  0.150D-01  0.540D-01  0.113D-01  0.830D-02   17
  18  0.126D-01  0.143D-01  0.666D-01  0.229D-01  0.222D-01  0.303D-01  0.507D 00  0.687D-01  0.149D-01  0.351D-01  0.111D-01  0.122D-01   18
  19  0.109D-01  0.162D-01  0.630D-01  0.245D-01  0.229D-01  0.311D-01  0.486D 00  0.523D-01  0.147D-01  0.279D-01  0.104D-01  0.111D-01   19
  20  0.102D-01  0.184D-01  0.386D-01  0.260D-01  0.235D-01  0.290D-01  0.375D 00  0.437D-01  0.139D-01  0.278D-01  0.102D-01  0.1[illegible]   20
  21  0.977D-02  0.205D-01  0.282D-01  0.274D-01  0.229D-01  0.278D-01  0.273D 00  0.368D-01  0.163D-01  0.214D-01  0.103D-01  0.9[illegible]   21
  22  0.961D-02  0.213D-01  0.298D-01  0.282D-01  0.225D-01  0.393D-01  0.203D 00  0.325D-01  0.400D-01  0.211D-01  0.948D-02  0.86[illegible]   22
  23  0.102D-01  0.176D-01  0.287D-01  0.347D-01  0.223D-01  0.454D-01  0.172D 00  0.288D-01  0.613D-01  0.153D-01  0.928D-02  0.785D-02   23
  24  0.119D-01  0.145D-01  0.245D-01  0.417D-01  0.221D-01  0.446D-01  0.151D 00  0.269D-01  0.650D-01  0.133D-01  0.989D-02  0.781D-02   24
  25  0.155D-01  0.135D-01  0.237D-01  0.327D-01  0.219D-01  0.429D-01  0.122D 00  0.245D-01  0.650D-01  0.143D-01  0.997D-02  0.908D-02   25
  26  0.178D-01  0.137D-01  0.237D-01  0.298D-01  0.217D-01  0.437D-01  0.108D 00  0.219D-01  0.568D-01  0.137D-01  0.903D-02  0.128D-01   26
  27  0.184D-01  0.140D-01  0.247D-01  0.266D-01  0.215D-01  0.406D-01  0.944D-01  0.249D-01  0.421D-01  0.128D-01  0.940D-02  0.141D-01   27
  28  0.163D-01  0.163D-01  0.258D-01  0.241D-01  0.213D-01  0.388D-01  0.850D-01  0.186D-01  0.264D-01  0.117D-01  0.912D-02  0.134D-01   28
  29  0.143D-01  0.185D-01  0.286D-01  0.221D-01  0.213D-01  0.374D-01  0.781D-01  0.177D-01  0.219D-01  0.108D-01  0.977D-02  0.131D-01   29
  30  0.133D-01  0.193D-01  0.274D-01  0.206D-01  0.0        0.397D-01  0.744D-01  0.204D-01  0.421D-01  0.105D-01  0.773D-02  0.181D-01   30
  31  0.116D-01  0.0        0.256D-01  0.200D-01  0.0        0.377D-01  0.0        0.287D-01  0.0        0.108D-01  0.104D-01  0.0         31


TOTAL 0.36[illegible]  0.459[illegible]  0.11[illegible]  0.740D 00  0.622D 00  0.978D 00  0.526D 01  0.147D 01  0.101D 01  0.764D 00  0.353D 00  0.341D 00

          TOTAL FOR WATER YEAR = 0.134D 02
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                                TENNESSEE VALLEY AUTHORITY ---- CONTINUOUS DAILY-STREAMFLOW MODEL


 DECREMENTERS FOR DELTAS
 1 0.50  2 0.50  3 0.50  4 0.50

 NROUND              SS      ICEPT                 PARAMETERS

 SEASON CHANGES:
 FALL=  15     WINTER=  92     SPRING= 183     SUMMER= 212

 READ IN ET VALUES BEGINNING WITH OCT. FOR WATER YEAR 1971
      1.63 0.70 0.1 0.0 0.02 0.14 0.06 3.76 5.27 4.91 4.51 2.53


 READ IN ET VALUES BEGINNING WITH OCT. FOR WATER YEAR 1972 :
      1.23 0.7  0.26 0.01 0.04 0.02 0.70 2.95 5.09 5.20 5.19 2.47
 B(1)=  0.315    E1= -0.933    B(2)=  0.286    E2= -0.374    B=  0.268    AA= -0.571    SSE=  0.113230 01
    0       0.114478040 01  0                   1       3.87187  2     52.50000  3     13.47187  4      0.15282
    1       0.114478040 01  0                   1       3.87187  2     52.50000  3     13.47187  4      0.15282
              DELTAS AT BEGINNING OF ROUND
                 1  0.00156250  2  0.00097656  3  0.00005493  4  0.00000017
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114470 01
       1            0.114478040 01        0.114499920 01        0.114489770 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
       2            0.114478040 01        0.114494820 01        0.114494860 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
       3            0.114478040 01        0.114494770 01        0.114494910 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
 B(1)=  0.295    E1= -0.556    B(2)=  0.268    E2= -0.005    B=  0.268    AA= -0.572    SSE=  0.114480 01
       4            0.114478040 01        0.114494840 01        0.114494840 01

 ** CONVERGED    ROUND=    1    TEST=    0.00050    SSE=         0.114478040 01

     PARAMETERS
  1      3.87187  2     52.50000  3     13.47187  4       0.15282
              DELTAS AT BEGINNING OF ROUND
                 1  0.00156250  2  0.00097656  3  0.00005493  4  0.00000017

 DECREMENTERS FOR DELTAS
 1 0.50  2 0.50  3 0.50  4 0.50

 YEAR  DAY  RAIN  SUR. V.  SUR. Q   GW V.    GW Q      ET   D S LOSS  ICEPT     SI    SURES  GW RESER  AHOR     BHOR     SMI       RI

 1971    1   0.0   0.0     0.0      0.0     0.0400  0.1584  0.0      0.0     1.0000  0.0      3.9600  0.0     0.8416  0.8416  0.32120 02
 1971    2   0.0   0.0     0.0      0.0     0.0396  0.1584  0.0      0.0     1.0000  0.0      3.9204  0.0     0.6832  0.6832  0.32120 02
 1971    3   0.0   0.0     0.0      0.0     0.0392  0.1584  0.0      0.0     1.0000  0.0      3.8812  0.0     0.5248  0.5248  0.32120 02
 1971    4   0.36  0.0005  0.0001   0.0382  0.0388  0.1584  0.0      0.0616  1.0000  0.0005   3.8596  0.0     0.6561  0.6561  0.16090 02
 1971    5   1.94  0.1019  0.0157   0.6797  0.0385  0.1584  0.0036   0.0616  1.0000  0.0458   4.4918  0.0     1.0533  1.0533  0.15670 02
 1971    6   0.0   0.0     0.0386   0.0     0.0449  0.1584  0.0      0.0     1.0000  0.0472   4.4468  0.0     0.9566  0.9566  0.15670 02
 1971    7   0.0   0.0     0.0212   0.0     0.0445  0.1584  0.0      0.0     1.0000  0.0260   4.4024  0.0     0.7982  0.7982  0.15670 02
 1971    8   0.0   0.0     0.0117   0.0     0.0440  0.1584  0.0      0.0     1.0000  0.0143   4.3583  0.0     0.6398  0.6398  0.15670 02
 1971    9   0.0   0.0     0.0064   0.0     0.0436  0.1584  0.0      0.0     1.0000  0.0079   4.3148  0.0     0.4814  0.4814  0.15670 02
 1971   10   0.0   0.0     0.0035   0.0     0.0431  0.1584  0.0      0.0     1.0000  0.0043   4.2716  0.0     0.3230  0.3230  0.15670 02
 1971   11   0.0   0.0     0.0019   0.0     0.0427  0.1584  0.0      0.0     1.0000  0.0024   4.2289  0.0     0.1646  0.1646  0.15670 02
 1971   12   0.33  0.0     0.0011   0.0     0.0423  0.1584  0.0      0.0     1.0000  0.0013   4.1866  0.0     0.0362  0.0362  0.15670 02
 1971   13   [illegible]
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                      TENNESSEE VALLEY AUTHORITY ---- CONTINUOUS DAILY-STREAMFLOW MODEL

FOLLOWING ARE PARAMETERS AND CONSTANTS FOR   ERAMOSA RIVER STREAMFLOW SIMULATION 1972 (TEST ONLY, NO OPTIMIZATION)
FOR YEAR(S) 1972-1972             ANALYSIS

DRAINAGE AREA =  91.00 SQ. MILES

   A        B       GWK      TDSRO     SROK      PIMP     BWORP    GRCKS    GRCKW
 3.972   52.500  13.472    0.153     0.550     0.100    1.650    0.990    0.910

 RSMI     RTMX      R       AWORD      HOF     *SOLID    GWDOR     DRF
 1.000    4.000   0.268    5.000     0.0       0.0     0.002    0.600

WINTER INTERCEPTION= 0.03     SUMMER INTERCEPTION= 0.22
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                     PATTERN SEARCH FOR OPTIMUM OF OBJECTIVE FUNCTION
                     FRAMOSA RIVER STREAMFLOW SIMULATION 1972 (TEST ONLY, NO OPTIMIZATION)
                 IOPT=  1   OPTIMIZE ON THE FOLLOWING
      1=SSE      2=WEIGHTED SSE      3=SUM OF ABSOLUTE ERRORS      4=SUM OF PREDICTIONS

     GRAPH RUNOFF FULL SCALE=       5.070D-01 INCHES               RAINFALL FULL SCALE=    5.

 DAY  OBSERVED      PREDICTED        ERROR            *****************************************************
   1  0.923870D-02  0.338610D-01 -0.246220D-01        * O P I    I    I    I    I    I    I    I    I    R*
   2  0.891160D-02  0.335210D-01 -0.246100D-01        * O P I    I    I    I    I    I    I    I    I    R*
   3  0.927950D-02  0.331850D-01 -0.239060D-01        * O P I    I    I    I    I    I    I    I    I    R*
   4  0.968840D-02  0.328530D-01 -0.231650D-01        * O P I    I    I    I    I    I    I    I    I    R*
   5  0.870730D-02  0.325240D-01 -0.238170D-01        * O P I    I    I    I    I    I    I    I    I    R*
   6  0.854370D-02  0.321990D-01 -0.236550D-01        * O P I    I    I    I    I    I    I    I    I    R*
   7  0.838020D-02  0.318770D-01 -0.234970D-01        * O P I    I    I    I    I    I    I    I    I    R*
   8  0.850290D-02  0.315750D-01 -0.230720D-01        * O P I    I    I    I    I    I    I    I    I R   *
   9  0.927960D-02  0.313570D-01 -0.220770D-01        * O P I    I    I    I    I    I    I    I    I  R  *
  10  0.112420D-01  0.311640D-01 -0.199220D-01        * O P I    I    I    I    I    I    I    I    I    R*
  11  0.145530D-01  0.307780D-01 -0.162250D-01        * O P I    I    I    I    I    I    I    I    I    R*
  12  0.142260D-01  0.304300D-01 -0.162040D-01        * O P I    I    I    I    I    I    I    I    I    R*
  13  0.122230D-01  0.301030D-01 -0.178800D-01        * O P I    I    I    I    I    I    I    I    I  R  *
  14  0.118550D-01  0.297900D-01 -0.179350D-01        * O P I    I    I    I    I    I    I    I    I    R*
  15  0.117320D-01  0.294850D-01 -0.177530D-01        * O P I    I    I    I    I    I    I    I    I    R*
  16  0.118550D-01  0.322400D-01 -0.203850D-01        * O P I    I    I    I    I    I    I    I    I    R*
  17  0.112830D-01  0.349070D-01 -0.236240D-01        * O P I    I    I    I    I    I    I    I    I    R*
  18  0.125910D-01  0.374770D-01 -0.248860D-01        * O  PI    I    I    I    I    I    I    I    I    R*
  19  0.109150D-01  0.399420D-01 -0.290280D-01        * O  PI    I    I    I    I    I    I    I    I    R*
  20  0.101790D-01  0.422970D-01 -0.321180D-01        * O  PI    I    I    I    I    I    I    I    I    R*
  21  0.977010D-02  0.445350D-01 -0.347650D-01        * O  PI    I    I    I    I    I    I    I    I    R*
  22  0.960660D-02  0.466960D-01 -0.370890D-01        * O   P    I    I    I    I    I    I    I    I R   *
  23  0.102200D-01  0.488270D-01 -0.386070D-01        * O   P    I    I    I    I    I    I    I    I    R*
  24  0.119370D-01  0.510010D-01 -0.390640D-01        * O   P    I    I    I    I    I    I    I    IR    *
  25  0.154930D-01  0.534950D-01 -0.380020D-01        *  O  P    I    I    I    I    I    I    I    I    R*
  26  0.178230D-01  0.550750D-01 -0.372520D-01        *  O  P    I    I    I    I    I    I    I    I    R*
  27  0.183950D-01  0.563060D-01 -0.379100D-01        *  O  IP   I    I    I    I    I    I    I    I    R*
  28  0.162700D-01  0.574980D-01 -0.412280D-01        *  O  IP   I    I    I    I    I    I    I    I    R*
  29  0.142670D-01  0.586030D-01 -0.443360D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  30  0.132860D-01  0.595950D-01 -0.463090D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  31  0.116100D-01  0.604590D-01 -0.488500D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  32  0.131630D-01  0.611910D-01 -0.480270D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  33  0.121410D-01  0.617820D-01 -0.496410D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  34  0.110370D-01  0.622370D-01 -0.512000D-01        * O   IP   I    I    I    I    I    I    I    I  R  *
  35  0.111600D-01  0.625560D-01 -0.513960D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  36  0.109150D-01  0.627390D-01 -0.518250D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  37  0.109560D-01  0.628330D-01 -0.518780D-01        * O   IP   I    I    I    I    I    I    I    I  R  *
  38  0.127130D-01  0.629440D-01 -0.502300D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  39  0.138170D-01  0.626970D-01 -0.488800D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  40  0.133270D-01  0.623530D-01 -0.490270D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  41  0.139810D-01  0.619410D-01 -0.479600D-01        * O   IP   I    I    I    I    I    I    I    I  R  *
  42  0.147570D-01  0.615590D-01 -0.468010D-01        * O   IP   I    I    I    I    I    I    I    I    R*
  43  0.165970D-01  0.608870D-01 -0.442900D-01        *  O  IP   I    I    I    I    I    I    I    I   R *
  44  0.172100D-01  0.602090D-01 -0.429990D-01        *  O  IP   I    I    I    I    I    I    I    I    R*
  45  0.151250D-01  0.593700D-01 -0.442450D-01        * O   IP   I    I    I    I    I    I    I    I   R *
  46  0.183140D-01  0.585880D-01 -0.402740D-01        *  O  IP   I    I    I    I    I    I    I    I    R*
  47  0.181500D-01  0.575400D-01 -0.393900D-01        *  O  IP   I    I    I    I    I    I    I    I    R*
  48  0.180280D-01  0.564410D-01 -0.384120D-01        *  O  IP   I    I    I    I    I    I    I    I    R*
  49  0.142670D-01  0.553960D-01 -0.411300D-01        * O   P    I    I    I    I    I    I    I    I    R*
  50  0.158880D-01  0.545130D-01 -0.386250D-01        *  O  P    I    I    I    I    I    I    I    I R   *
  51  0.183550D-01  0.534650D-01 -0.351100D-01        *  O  P    I    I    I    I    I    I    I    I   R *
  52  [illegible]   [illegible]   [illegible]         *  O  P    I    I    I    I    I    I    I    I    R*
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